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# Developing the 3D Mechanical Engineering Process for a Large Manufacturing Company

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Regardless of the type, purpose and result of any work being done, people are always behind it. On the very first page next to the title of this work is my name. But in reality, a list of names of all persons who participated in this project would take a separate page. Starting from the very beginning of this work, with the definition of the goal and the end result, I always felt the support and desire to help from those around me.

First of all, I would like to express my gratitude to the company, which gave me the opportunity to show my skills and develop new ones. I thank all designers, all heads of departments, members of the supporting organization, and representatives of another company of the case organization, who took part in this Thesis. I want to thank them for the atmosphere of teamwork, for honesty during the interviews, for provided materials, advice, feedback and efforts in developing this process. I was happy to be surrounded by such high-class specialists and to observe the organizational changes taking place in real time.

Thanks to the education provided by Metropolia University of Applied Science, this work became possible. Without all the knowledge gained during this program, this work could not be accomplished so effectively and professionally. From the first day our instructors, visitors and students began to form the foundation for further fulfilment of the study's tasks and development of professional skills. I would like to thank my instructors for their high professionalism in teaching, the knowledge and contribution they have made in writing this work. I am also grateful to all visitors for the opportunity to get acquainted with the practices of industrial management in various business segments. I want to express special gratitude to the students who studied with me. We were all in the same boat. Despite the difference in nature and scope of our works, we were always ready to support each other and provide advice.

Finally, I want to emphasize the contribution of my family. My closest people served me and gave support in difficult times, and I could always rely on their kindness. In particular, I thank my parents and spouse for the high understanding of the importance of this work for me, their patience, endurance, and all those kind words that I heard from them.

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This Thesis focuses on developing the 3D mechanical engineering process for a Large manufacturing company. Several years back a new 3D software was introduced to three engineering departments, but without a process how to utilize this new software. Due to the lack of initially developed process, the company cannot utilize true benefits of new software, which results in overlapping responsibilities, quality issues and schedule problems. Therefore, the case company needs to develop the 3D engineering process to undertake mechanical engineering in a coordinated way.

In this study, the case study approach and qualitative research methodology were utilized due to a complex and specific nature of the research problem and need for in-depth exploration of the phenomena. The research design of this Thesis consists of five pre-defined steps, three data collection rounds and specified expected outcome from each practical step. The data was collected within the case company through interviews, documentation analysis and workshops. In this study, the current state analysis was done first to get in-depth understanding of the current 3D engineering practices in the case company, which was followed by the literature review focused on identified weaknesses and subsequent proposal building.

This Master's thesis revealed difficulties in adapting a new software in engineering processes of the large manufacturing company. In the current state analysis, the key findings related to the lack of a defined workflow, inefficient distribution of roles and responsibilities for process development and support, and lack of communication and collaboration within the engineering departments. Based on utilizing the conceptual framework developed during the literature review and the stakeholder's suggestions, the study proposes cross-functional improvements that the case company can use to develop and deliver an effective engineering work.

By utilizing the proposed practices, the case company can improve its 3D mechanical engineering processes, develop a common standard for performing engineering work and in the long run reach the level where 3D technology can support engineering process's performance using process reconfigurations, and allow analysis of environmental changes. This study shows the logic of building a new process in the cross-functional context on a local scale taking into account internal features of different departments and partly the impact of the global environment. The proposed practices are approved by the case company and will be used in the near future. At the time of the completion of the study, the company began to implement changes in accordance with the proposed action plan.

| | |
|---|---|
| Keywords | 3D Mechanical Engineering, Process development, Workflow modeling, communication, collaboration, Process re-engineering, Continuous improvement |

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# 1 Introduction

Due to a continuously changing business and technology environment, engineering teams and departments are forced to improve their processes and utilize new opportunities. In the same time, engineers face many challenges, such us complexity of structures, design, workflows and demanding customers. For example, it is well known that, for large manufacturing and engineering companies, is extremely important to provide services and products in accordance with customer's expectations. This is needed in addition to utilizing own operating models and activities in most efficient way and achieving a desired level of income. As such, engineering has a strong impact on the company's product quality, serviceability and operating activities. Therefore, the efficiency and performance of engineering departments and teams is critical for the success of any manufacturing or engineering company.

By utilizing 3D modeling solutions, a company may increase its engineering efficiency, avoid costly mistakes, and gain more precision and control. Nevertheless, quite often engineering suffers from the lack of an effective approach to the implementation of certain tasks with the solutions. As a result, engineering process becomes cost ineffective. A similar situation appeared in the case company, which has an urgent need to develop an effective 3D engineering process.

## 1.1 Business Context

The case organization of this study is a multinational corporation operating mainly in robotics and the power and automation technology areas. The organization is divided into four Business Units such as [redacted]

The case company of this study is one of the production units of BU[redacted], located in Helsinki. The company is a large manufacturer of electrical motors and generators. The company operates in the field where high quality, employees experience, skills, and adherence to international standards are an integral part of business. High technological level of products implies the fulfillment of a large number of tasks in accordance with a developed plan combined in the production process. Therefore, organizing of these tasks in complex processes has a great impact on the success of the company.

When working closely with a large number of other departments and sometimes directly with a customer, engineering departments have a great responsibility for outcome. The use of modern software can help to improve the quality of engineering work, but only in the case of a well-developed process.

## 1.2 Business Challenge, Objective and Outcome

In the case company, for ensuring maximum accuracy and efficiency over engineering departments' activities, a new 3D software was introduced several years ago. Asynchronous machines and Synchronous machines mechanical engineering departments and R&D got the opportunity to use the new software. In the company, R&D department is responsible for product development; while mechanical engineering departments are responsible for preparation of manufacturing and customer documentations, and product structure, working closely with R&D, sales, management, purchasing, production planning departments and manufacturing units. Although the internal processes and product families of mechanical engineering departments differ to some extent from each over, using the common storage and data processing systems requires awareness of the actions of each department.

Due to the lack of initially developed engineering process and operating model in accordance to the new software, the case company cannot presently utilize the software and thus realize true benefits from it. As a result, the current use of company’s resources is inefficient and cooperation within engineering departments is practically absent.

The objective of this Master’s Thesis is *to develop a 3D engineering process for the three departments to undertake mechanical engineering in a coordinated way.* The new process would help the case company to develop and deliver an effective engineering work, and increase cooperation within three engineering departments. The expected outcome of this study is a new 3D mechanical engineering process developed taking into account three engineering departments’ internal processes and operating models.

## 1.3 Thesis Outline

To obtain full information about the existing problem, the engineering processes of the three departments were analyzed as well as an analysis of the technical capabilities of the systems conducted by an outsourcing company in 2016. Quality of the work, satisfaction with the new software, possible wishes and obvious problems were analyzed based on interviews with key stakeholders. Gathered information showed the real level of personnel skills, differences in specific working processes and common interests of departments. The theory of process development was collected from literature.

This study is written in seven sections. Section 1, Introduction, describes the background and overviews the thesis. Section 2, Method and material, explains *how* the study is conducted. Section 3, Current state analysis, explores the current practices of the 3D engineering process in the case company. Section 4, Best Practice, overviews best practice from the topics of process development, workflow modeling, cooperation and process roles and responsibilities in large engineering companies. Based on these practices the section suggests a conceptual framework for the process development. Section 5, Building the proposal for the case company, based on the conceptual framework, proposes 3D engineering concept. Section 6, Validation of the proposal, discusses results of validation process of the proposed concept. Section 7, Conclusions, summarizes the thesis and propose future directions for development.

## 2 Method and Material

This section introduces the research method and data that were applied in this study. Firstly, the section describes research approach, research design and demonstrates *how* the study was constructed. Secondly, the section discusses the data collection and analysis methods, after which a plan for the reliability and validity of the study is explained.

### 2.1 Research Approach

Any research is mainly related to the creation of new knowledge. The basis of new knowledge creation is clearly defined method and source of data collection that a researcher identified as deserving of analysis. Good practice of data collection largely depends on research approach selection based on the nature of the research problem. (O’Gorman & Macintosh 2014, 75.) The selection of a research approach depends on the environment in which the project arises, including experience of the researcher and type of involved audience (Creswell 2014, 20). Due to a complex and specific nature of the research problem and need of in-depth exploration of the phenomena, the case study approach is selected as a methodology for this study.

The case study approach is one of the most common approaches used in business researches which includes a detailed analysis of phenomena, usually based on data collected over time (Dul & Hak 2008, 4-5). According to Yin (2003) a case study is “an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between object of study and context are not clearly evident”. The main goal of the case study approach is to create an analysis of context and processes that illuminate the roots of the problem being investigated. The phenomenon is not separated from its context, but rather aims to understand how behavior and processes influence and depend on the context. (O’Gorman & Macintosh 2014, 80.)

A case study can be single or multiple and basically focused on one or more specific objects, such as organizations, departments, teams, individuals, processes and programs. The approach is particularly effective for examining “Why”, “How” and “What” questions and for this reason the case study approach is often used for theory development and testing. Case studies usually begin with a difficult situation, which is not well understood and poorly explained. The aim is therefore to understand the current problem and use the information gained to develop a new theoretical view or explanation. (O'Gorman & Macintosh 2014, 81.)

As was discussed previously a case study is an in-depth study focused on a specific phenomenon. Therefore, case studies basically are qualitative in nature and utilizes qualitative data collection and analysis methods which are typically divided into four primary groups: observations, participant observations, in-depth interviewing, and review of documents (Marshall & Rossman 2006, O'Gorman & Macintosh 2014). Qualitative methods provide an opportunity to collect valuable data and to obtain a richer understanding of the problem and uncover false results (O'Gorman & Macintosh 2014, 118).

Despite the qualitative nature, the case study approach can utilize qualitative and quantitative or both data collection methods. Using of multiple sources of data can increase the validity of a study and allow to develop more holistic picture of the phenomenon. For example, evidence of documentation can be used to verify the evidence obtained during the interview. (O'Gorman & Macintosh 2014, 118.)

In this study the case study approach and qualitative research methodology are selected due to a complex and specific nature of the research problem and need of in-depth exploration of the phenomena. The study utilizes multiple data collection methods such as workshops, interviews, observations and document reviews that provide a reliable foundation for a detailed analysis of the obtained information. The qualitative data collection method is also selected due to a difficult collection and presentation of statistical data.

The study provides an all-encompassing description of real-life situation, focused on three specific engineering departments in terms of one context as a single case study and answer the "*what is wrong*", "*why it is wrong*" and "*how to improve*" questions. The study was designed by utilizing case study approach characteristics and the design is presented and described in the next sub-section.

## 2.2 Research Design

This sub-section describes the research design in this study and explains its key elements. The research design is built as step-by-step process and shown in Figure 1 below, including data collection rounds and expected outcome of each step.

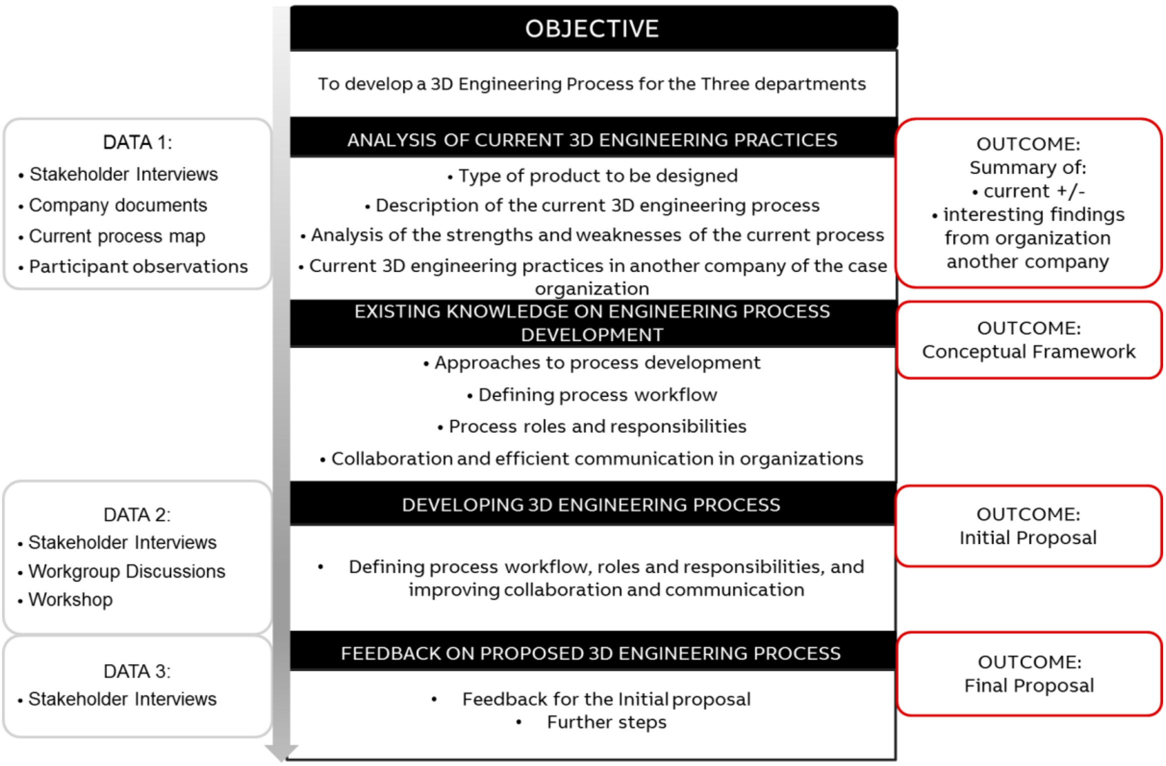



Figure 1. Research design of the study.

As shown in Figure 1 the research design includes five main steps with three data collection rounds and specified expected outcome from each practical step. An absolutely first step of the study is defining objective and outcome of the study. The case company has determined the business challenge which defines the objective, which is to develop a 3D engineering process for the three engineering departments. The expected outcome of this study is a new 3D engineering process.

After the objective and outcome were defined, the Current State Analysis (CSA) was conducted to get in-depth understanding of the current 3D engineering practices in the case company. The CSA is based on collected through various sources Data 1 and identifies key strengths and weaknesses of the current 3D engineering practices and interesting findings from another company of the case organization.

Due to unclear nature of the phenomena, the literature review was made after the CSA. The literature topics, ideas and concepts of process development were selected based on findings from the CSA. Found from literature best practice figured the Conceptual Framework, which together with the CSA and Data 2 was utilized during the next step in building the initial proposal for the 3D engineering process. The initial proposal was validated and discussed by key stakeholders and modified utilizing Data 3. Subsequently, the final proposal was made for the 3D engineering process for the case company.

## 2.3 Data Collection and Analysis

In this study, the data was collected from a number of data sources and, as shown in Figure 1 and Table 1, in three data collection rounds: Data 1 as part of the CSA, Data 2 for building the proposal and Data 3 for validating the proposal. The sources for data collection rounds cover all three departments for which proposal was developed to ensure higher level of evidence.

Table 1. Data collection rounds Data 1-3.

| Data | Data sources | Purpose | Analysed in |
|---|---|---|---|
| Data 1, CSA | 1. Internal documents<br>• Memos, reports<br>• Analysis of technical process & capabilities<br>• Internal portals<br>• Standards, instructions | Identifying key elements of current 3D engineering process:<br>- Type of product to be designed<br>- Description of the current 3D engineering process<br>- Strengths and weaknesses of the current process | Section 3, CSA |
| | 2. Participant observation | | |
| | 3. Interviews with stakeholders<br>4. Process mapping | | |
| | 5. Interviews with PLM global application manager and key stakeholder from another company of the case organization | Overview and description of processes in another company of the case organization | |
| Data 2, Building the proposal | 1. Interviews with stakeholders<br>2. Workgroup discussion<br>3. Workshop | Suggestions for building the proposal related to:<br>- Defining process workflow<br>- Defining roles and responsibilities<br>- Improving communication and collaboration | Section 5, Building the proposal |
| Data 3, Validating the proposal | 1. Interviews with stakeholders | Identifying improvement ideas to initial proposal<br>Evaluation of proposal | Section 6, Validation |

Table 1 briefly overviews Data collection rounds 1-3 for this study. As seen from the table, the study utilizes various types of data collection sources such as interviews, discussions, workshops, participant observations and document reviews. The sources are explained more detailed below. Figure 1 also presents the main purpose of each data collection round and in which section the data was analyzed.

Table 2 below provides further details related to the interviews and participant observations made as part of the CSA, Data 1. The aim of this data collection round was to gain an understanding of the current 3D engineering process.

Table 2. Details of Data collection Data 1.

| | Role | Data type | Topic | Date and Length | Docu-mented |
|---|---|---|---|---|---|
| 1. | Senior mechanical designer (Asynchronous machines) | Face to face interview | • Type of product to be designed<br>• Description of current 3D engineering process<br>• Strengths and weaknesses of the current process | 17.1.2018 52 min | Field notes |
| 2. | Super-user (Synchronous machines) | Face to face interview | • Type of product to be designed<br>• Description of current 3D engineering process<br>• Strengths and weaknesses of the current process | 16.1.2018 50 min | Field notes |
| 3. | Local application owner | Face to face interview Process mapping | • Type of product to be designed<br>• Strengths and weaknesses of the current process<br>• Illustration of current process | 23.1.2018 37 min | Field notes Process map |
| 4. | Global application owner (ex. Super user, R&D) | Face to face interview Process mapping | • Type of product to be designed<br>• Description and illustration of current 3D engineering process<br>• Strengths and weaknesses of the current process | 18.1.2018 62 min | Field notes Process map |
| 5. | Global application manager | Face to face interview | • Strengths and weaknesses of the current process<br>• 3D engineering practices in another company of the case organization | 23.1.2018 39 min | Field notes |
| 6. | Head of R&D department (Another company of the case organization) | Face to face interview | • 3D engineering practices in another company of the case organization | 1.2.2018 62 min | Field notes |
| 7. | Head of engineering department (Asynchronous machines) | Face to face interview | • Summary of strengths and weaknesses of the current process<br>• Improvement opportunities | 8.2.2018 10 min | Field notes |
| 8. | Synchronous machines engineering department | Participant observation | • Strengths and weaknesses of the current process | December-February | Field notes |

| | | | | | |
|---|---|---|---|---|---|
| 9. | Asynchronous machines engineering department | Participant observation | • Strengths and weaknesses of the current process | December-February | Field notes |

As shown in Table 2, the data for the CSA based on seven interviews, two process mapping sessions and participant observations. The interviewees were chosen based on their position inside the case company, experience and role in the current process development. Four types of question templates were utilized during this data collection round due to a specific purpose and type of data being investigated. The questions were created in advance and sent a week before the interview. Face-to-face interviews were held inside the case company, recorded and documented in field notes with subsequent checking and corrections by interviewees. Data 1 field notes can be found in Appendices 1-4. Process mappings were conducted immediately after the interviews and documented in process map with subsequent comments by interviewees. The illustration of Data 1 process map can be found in Appendix 5. The observations were collected from researcher's experience that have been accumulated during the period of working in both mechanical engineering departments, cooperating with R&D department.

Along with Data 1 interviews, process mapping sessions and observations, a documentation were analyzed in this round. This documentation focused on the analysis of technical capabilities of 3D software and PDM systems made by an outsourcing company in 2016 and other internal documentation of the company listed below.

Table 3. List of internal documentation used in Data collection 1, CSA.

| | Name/type of document | Volume | Description |
|---|---|---|---|
| 1. | Design review: analysis of technical capabilities | 300 p. | Analysis of technical process & system capabilities made by external company |
| 2. | Development cases: categorization table | 5 p. | List of categorized development cases related to 3D software/engineering process |
| 3. | 3D Best practice development group memos | 9 pcs. | Development group memos and field of notes from last year |
| 4. | Asynchronous machines engineering department | Web | Sharepoint portal for sharing internal and external instructions |
| 5. | Synchronous machines engineering department | Web | Sharepoint portal for sharing internal and external instructions |
| 6. | R&D portal | Web | Sharepoint portal for sharing internal and external instructions |

| | | | |
|---|---|---|---|
| 7. | Engineering instructions and standards | Web | Internal database for sharing instructions and standards |
| 8. | Internal knowledge database | Web | Internal database for sharing instruction |

As shown in Table 3, a variety of company documents, including internal web-portals, and pages was reviewed to getting better understanding of the current process practices and engineering environment.

In the next data collection round, Data 2 was collected to gather suggestions from the key stakeholders. Data 2 includes four face-to-face interviews, one workshop and discussions listed below. Table 4 below shows details of Data 2 collection.

Table 4. Details of Data 2 collection.

| | Role | Data type | Topic | Date and Length | Documented |
|---|---|---|---|---|---|
| 1. | Senior mechanical designer (Asynchronous machines) | Face to face interview | • Building the proposal<br>• Process characteristics | 3.4.2018 40 min | Process map (draft) Process characteristics |
| 2. | Super-user (Asynchronous machines) | Face to face interview | • Building the proposal<br>• Process characteristics | 29.3.2018 40 min | Process map (draft) Process characteristics |
| 3. | Global application owner | Face to face interview | • Building the proposal<br>• Process characteristics | 3.4.2018 90 min | Process map (draft) Process characteristics |
| 4. | Local application owner | Face to face interview | • Building the proposal<br>• Process characteristics | 4.4.2018 120 min | Process map Process characteristics |
| 5. | Asynchronous machines engineering department | Workshop | • Ideas on engineering process development | 20.3.2018 90 min | Notes |
| 6. | Head of engineering department (Asynchronous machines) | Face to face discussion | • Building the proposal<br>• Process characteristics | 3.4.2018 30 min | Process characteristics |
| 7. | Head of engineering department (Synchronous machines) | Face to face interview | • Building the proposal<br>• Process characteristics | 5.4.2018 30 min | Process characteristics |

In Data 2 collection, the interviews were conducted in the same manner as in Data 1. The workshop was held with Asynchronous machines engineering department designers, as a part of planned team meeting, ensuring a high level of group productivity and reliability. During the workshop, ideas on mechanical engineering process development were proposed by designers and openly discussed. During the individual discussions held with the stakeholders and interviews with heads of engineering departments, the process characteristic and key focus areas of 3D mechanical engineering process development were introduced and discussed step-by-step with later corrections and additions.

The third data collection round, was conducted to produce the final proposal for 3D engineering process. Data 3 included the same number of meetings as Data 2, except for face-to-face interviews with key-users. The data collection for Data 3 is presented in Table 5 below.

Table 5. Details of Data 3 collection.

| | Role | Data type | Topic | Date and Length | Documented |
|---|---|---|---|---|---|
| 1. | Senior mechanical designer (Asynchronous machines) | Face to face interview | • Evaluate improved practices | 6.4.2018 | Field notes |
| 2. | Senior mechanical designer (Asynchronous machines) | Face to face interview | • Evaluate improved practices | 11.4.2018 | Field notes |
| 3. | Local application owner | Face to face interview | • Evaluate improved practices<br>• Next steps | 10.4.2018 | Field notes |
| 4. | Global application owner | Face to face interview | • Evaluate improved practices<br>• Next steps | 10.4.2018 | Field notes |
| 5. | Head of engineering department (Synchronous machines) | Face to face interview | • Evaluate improved practices<br>• Presentation of final proposal | 11.4.2018 | Field notes |
| 6. | Head of engineering department (Aynchronous machines) | Face to face interview | • Evaluate improved practices<br>• Presentation of final proposal | 11.4.2018 | Field notes |

In the validation stage, after the corrections and other developments, the initial proposal was introduced to the stakeholders. Together with the stakeholders, the final proposal was created by utilizing suggestions, ideas, maps and concepts from previous meetings and documented in field notes and new process map. The final proposal was presented to heads of engineering departments and validated during the meetings.

All the collected data for this study were analyzed by using Thematic content analysis. The biggest part of data collection was done at the CSA stage to find out the current state of the 3D engineering process in the case company. The findings and analysis of collected Data 1 are discussed in Section 3 below.

# 3 Current State Analysis of the Existing 3D Engineering Practices in Three Departments

The section discusses the findings from the current state analysis and their significance relating to two mechanical engineering departments and R&D department. The section points to the strengths and weaknesses of the practices and provides a summary of key findings.

## 3.1 Overview of the Current State Analysis Stage

The current state analysis aims to provide an in-depth overview of the current 3D engineering practices in the case company. As was discussed previously in Sub-section 1.2, the lack of initially developed engineering process and operating model in accordance to the new software negatively hinders the engineering work. Nevertheless, the case company makes efforts to develop the process. For getting better understanding of the current situation, the current state analysis of the current 3D engineering practices was conducted in six steps. The analysis was based on the data received from interviews with key stakeholders, the overview of internal documentation, mapping sessions and participant observations. The steps are described below.

First, the current state analysis describes the current organizational model regarding 3D engineering process. The description helps to examine informant selection logic, the scope of the problem and roles of the departments. Second, the types of designed products are described and listed in accordance with their characteristics when working in the 3D software. Third, the current 3D mechanical engineering process is described and analyzed in parts. Since at the moment there is no clear process in the company, the section describes the current situation in detail to obtain a complete picture of the current 3D engineering practices in the case company. Fourth, based on the received and processed information during Data 1 collection round, the strengths and weaknesses of the current process are identified. Fifth, due to the large size of the case organization and widespread use of the 3D software inside it, the state of the process in another company of the case organization was discussed with a description of the findings. Finally, the summary of key findings is presented which points to the findings from these steps.

### 3.2 Organizational Structure of the Case Company

The case company is a part of the Production group (PG) of one of the case organization's Business Units. The PG [redacted] consists of several production units (PU) around the world. The case company is a PU which in the whole order-to-delivery process is responsible for product engineering, purchasing, and manufacturing supported by project management. The manufactured products have many variations and the end design of each machine is unique.

Presently, the project specific design process consists of electrical and mechanical engineering. Synchronous and Asynchronous machines engineering departments of the case company have their own electrical and mechanical engineering teams, which are supported by common R&D department. R&D department has a variety of teams divided according to the type of designed products or the type of tasks performed. Responsibilities of R&D department are product development, initial design, creating of standard materials, components and instructions. Synchronous and Asynchronous engineering departments are responsible for creating required customer documentation. Also, the departments ensure manufacturability of all the mechanical details and prepare product structure in PDM system. The R&D and the mechanical engineering teams are using the 3D software in designing of machine's components and drawings.

Regarding the support for this 3D software, Support organization supports the use and development of PDM and CAD (including 3D) systems in the case company. The Support organization includes Global and Local Supports. The Global support is responsible for supporting all BU's Production Units which use PDM and CAD systems. The Local Support of the case company consists of key-, super-users and local application owner.

Figure 2 below represents a simplified structure of this organization in the case company.

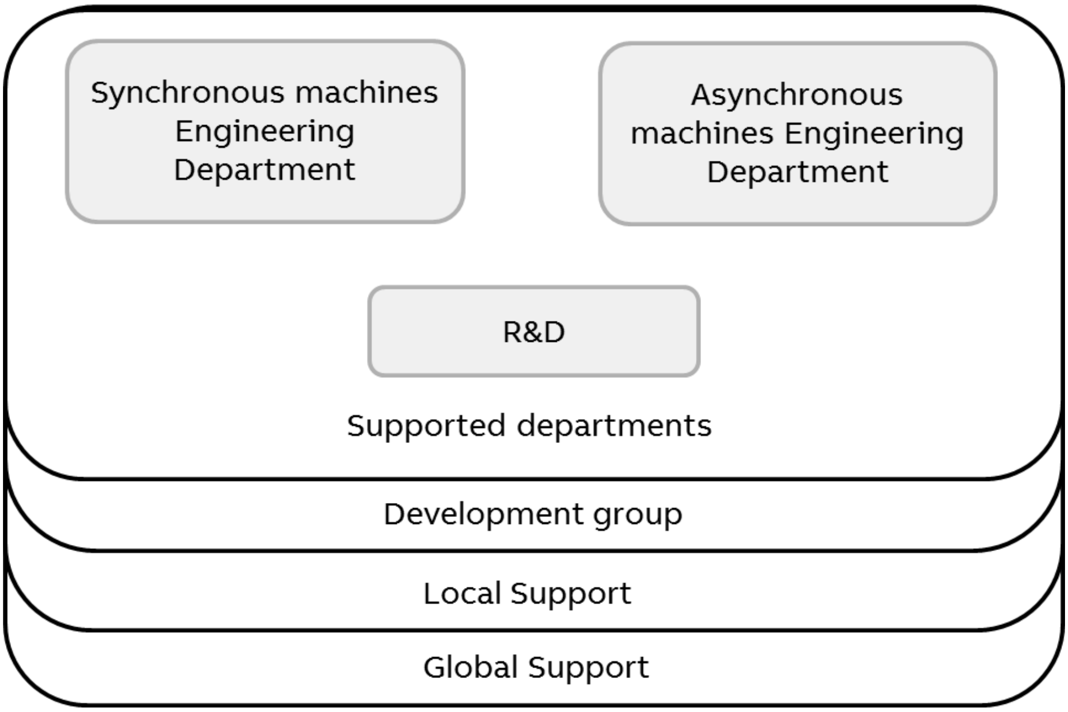



Figure 2. Support Organization (CAD and PDM systems) in the case company.

As seen from Figure 2, the Local Support also includes a process development group whose goal is to develop the 3D process in the case company. The group determines a necessary improvements or ideas for development and requests them from Global Support organization. The company is ultimately responsible for own local processes and Global Support is the technical implementer, which can consult, advice, giving an opinion on software development ideas.

Since the organizational structure includes distributed roles by departments, a more detailed company structure regarding the 3D engineering process is described in Sub-section 3.4.

## 3.3 Types of Products and Components to Be Designed

Due to a long history of the case company, there are many variables of products to be designed. As was discussed earlier in Sub-section 1.2 the product families of mechanical engineering departments differ to some extent from each over. Nevertheless, the designed products and components can be grouped according to characteristic features, such as complexity of modeling and frequency of use. This sub-section briefly overviews main types of designed products and components.

The list of designed products was created based on a review of most common machines' structures in PDM system, a review of standards and instructions, and discussions with key stakeholders. The types of designed products and components were categorized for further more detailed analysis. The categories were distributed in such a way that they could be utilized most efficiently during the decision-making process. First, the categories are defined for both types of machines in general terms based on the complexity of the 3D design. Table 6 below represents the main categories of the designed products.

Table 6. Types of products and components to be designed, categorized by design difficulty level.

| Difficulty level | | Description |
|---|---|---|
| A | A1 | Small sized or simple part or component, modeling does not require special skills. |
| | A2 | More complex components or parts, longer design time, requires specialized knowledge of the product. |
| B | B1 | Simple assemblies, does not require special skills. |
| | B2 | More complex assemblies consisting of a large number of components, require special knowledge of the product. |
| C | C1 | Complex parts or assemblies consisting of several stages of modeling. Particular expertise is required on products and systems. Usually does not require the use of special licenses. |
| | C2 | Difficult complex entities, long modeling time. Require special training, special licenses and knowledge of products and system. |

As seen from Table 6, the products and components are divided into three categories and six levels of complexity. Level A1 includes small, easy-to-design, bulk or standard components which creation does not require special skills in 3D modeling. Level A2 includes more complex components or parts, which modeling require some special knowledge of the product.

Difficulty on Level B1 consists of simple, often auxiliary assemblies. Level B2 includes large assemblies which modeling in 3D requires some special knowledge of modeling principles and logic. Updating of such components is complex and modeling time is longer.

Level C assemblies and components are large and complex. The parts consist of a massive number of items or modified surfaces and special design features. In addition to good enough engineering experience, the creation of C1 models requires a special and deep knowledge of CAD and PDM systems. Designing of Level C2 models also requires special training and using of additional licenses.

Table 6 clarifies the general principle of dividing the products and components by complexity level. In the following sub-sections, more detailed description of designed models is presented.

### 3.3.1 Synchronous Machines

Synchronous machines are one of the types of products the case company produces. Planned engineering time of synchronous machines usually lasts from several weeks to several months, depending on the model and type of products or specificity of additional components. These products usually consist of a large number of components. The components can be divided into several categories such as standard, unique design or subcontracting parts. Table 7 below presents the classification of these components' types, average availability of their 3D models in PDM system and estimated frequency of use.

Table 7. Types of components to be designed. Synchronous machines.

| Difficulty level | Examples | Type | Availability of 3D models | Frequency of use |
|---|---|---|---|---|
| A1 | Washers, screws, bolts, nuts | Standard items | Mostly available | Constant frequent use |
| | Material sheets | Special design | Depending on design | Frequent use |
| A2 | Bearings, transformers etc. | Subcontracting parts. Catalog products. | Rarely available | Once during the project |
| | Shafts | Special design | Depending on design | Once during the project |
| B1 | Tachometers, sensors | Subcontracting parts. Catalog products. | Rarely available | Once during the project |
| | Mounting plates, brackets | Special design | Depending on design | Once during the project |
| B2 | Terminal boxes, intermediate boxes, enclosures | Special design or standard items | Mostly available | Constant frequent use |
| | Carbon brush assemblies and enclosures | Special design | Depending on design | Once during the project |

| | | | | |
|---|---|---|---|---|
| | Packages | Special design | Depending on design | Once during the project |
| C1 | Frames | Special design | Depending on design | Once during the project |
| | Heat exchangers | Special design | Depending on design | Once during the project |
| | Bearing pedestals and shields | Special design | Rarely available | Once during the project |
| | Diode bridges | Special design | Depending on design | Once during the project |
| C2 | Rotor poles | Special design | Available but depends on the type | Once during the project |
| | Stator | Special design | Rarely available | Once during the project |
| | Piping and cabling | Special design | Rarely available | Rare use |
| | Transformer platforms | Special design | Available but depends on the type | Once during the project |

As seen from Table 7, most of the components have special design depending on the certain type of machine. Nevertheless, that does not necessarily mean the need to design each specific component during the new project. In many cases there are already existing components, which can be used in case they will be found in PDM system by designer. Also, the absolute majority of the components is used once during the project. Thus, if the existing component is found, the engineering time of the machine can be drastically reduced.

Standard items are protected by internal or/and external standards. The items have specific design and defined attributes. Usually R&D department is responsible for their updating and creation. Standard items are used quite often and are part of large assemblies. Subcontracting components also have a specific design, which is created by a third-party company. Often such 3D models are rarely available, and creating of 3D models according to available suppliers' drawings and brochures is a complicated process due to the complexity of surfaces.

Asynchronous and Synchronous machines engineering departments have common libraries of standard items listed in internal database. The libraries includes materials, standard components and in some cases lists of items' ID numbers. Despite the common base of standards, the differences between designed products in most cases do not allow to use the same components. At the same time, some common components are used with different periodicity in the departments. For this reason, a similar to Table 7 list was created separately for asynchronous machines.

### 3.3.2 Asynchronous Machines

Asynchronous machines are the second type of products produced by the case company. Traditionally, asynchronous machines are smaller and consist of fewer components than synchronous machines. For asynchronous machines, the projects’ lead time, compared to synchronous machines, is considerably shorter and engineering time usually takes only several days. More complex projects can last several weeks. Typically, machines have a standard structure, differing in component sets and special customer requirements. Table 8 below presents the asynchronous machines’ components, classified on the same principle as the synchronous machines’ components.

Table 8. Types of products and components to be designed. Asynchronous machines.

| Difficulty level | Examples | Type | Availability of 3D model | Frequency of use |
|---|---|---|---|---|
| A1 | Washers, screws, bolts, nuts | Standard items | Mostly available | |
| | Material sheets | Special design | Depending on design | |
| | Bearing | Standard items | Rarely available | |
| A2 | Auxiliary terminal box mounting plate Module frames | Special design | Not available | |
| | Shafts | Special design | Available for 2 product lines<br>Mostly not available | |
| B1 | Mounting plates | Special design | Not available | |
| | Auxiliary terminal box mounting plate Cast frames | Special design | Mostly available | Rare use |
| B2 | Heat exchanger | Special design | Mostly not available | |
| | Fan covers | Special design | Mostly not available | |
| | Intermediate box | Special design | Mostly not available | |
| C1 | Welded and machined assemblies: frames, bearing shields etc. | Special design | Mostly not available | |
| C2 | Piping and cabling | Special design | Not available | |
| | Bearing assemblies | Special design | Rarely available | |
| | Fans | Special design | Mostly not available | |

As seen from Table 8, the main part of the components is not available in the 3D format. There are some exceptions, for example, two product lines are initially designed in 3D, which means that at least frames, shafts and other active components are also available in 3D for these products. In general, the department’s engineers are rarely forced to use 3D software, but in the case of complex or special projects, the absence of 3D models affects the engineering time. Also in the future, the use of 3D technology in this department will be expanded, so the development of the process for this department is a necessity.

The lists of designed components and complexity levels are also utilized and discussed in details in Section 5, related to the building of proposal.

## 3.4 Description of the Current 3D Engineering Process

Due to the lack of initially developed and described process, 3D mechanical engineering works as an AD-hoc process. Despite the flexible nature of the AD-hoc process, the company cannot presently efficiently utilize the software and thus realize real benefits from it, as was discussed previously in Section 1.

In connection with the existence of Support organization and Development group, the description of the process includes a description of the current development practices as an integral part of the environment. These practices have a direct impact on the process, interacting with it at all steps and creating the prerequisites for its successful development. The current development practices have their strengths and weaknesses and, therefore, are discussed before the description of the 3D engineering process, including the distribution of the key roles and responsibilities. Consequently, the main steps of the current 3D engineering process are overviewed and discussed separately and more deeply.

### 3.4.1 Current Development Practices

As discussed previously in Sub-section 3.2, the Local Support and Development group determine necessary improvements or ideas for development and requests them from Global Support organization. Development group mainly consists of Local support's members with representatives of Global Support organization also. Required participants are Global Support's 3D experts and key stakeholders of the case company. The group includes representatives of R&D and Synchronous machines departments only, due to the lack of key roles in terms of 3D software in Asynchronous machines department.

Nevertheless, according to documented Development group's principles, the atmosphere of meetings is open and there is a possibility to invite other experts from the case company. The current roles and responsibilities are listed in Table 9 below.

Table 9. Roles and responsibilities of Development group participants in the case company (Case company, 2017).

| Role | Responsibility | Allo-cation | Available resources |
|---|---|---|---|
| Key-users | - Responsible for application training, instruction creation and updates<br>- Responsible for 1st level user support<br>- Works under the guidance of Local Application Owner representing meetings | 20% | 3-4 |
| Super-users | - Responsible for application training, instructions creation and updates. Based on Local Application Owner's instructions, communicates the application changes to the local organization.<br>- Responsible for 1st level user support. When needed, transfers queries and support requests to Global support organization working as a contact person between local users and Global Support organization<br>- Works under the guidance of Local Application Owner representing meetings<br>- Point out the needed proposals for application improvement and corrective activities together with Local Application Owner.<br>- Working as a main responsible for user acceptance testing in local site.<br>- Specifies and maintains local test cases and testing activities.<br>- Secure that the local site will be fully compatible with the other sites in BU and its architecture as a whole will be appropriate, secure, continuous and reliable. | 40% | 3 |
| Local application owner | - Arranges necessary application training, support, operation and maintenance work in the local PDM site including all installations (servers/clients) and environments (production/test/development)<br>- Keeps the local key user community strong enough and agree clearly the named persons with their superiors/line managers<br>- Owns the contract in case of local agreements with internal or external service providers<br>- Verifies the quality of service deliveries from internal or external service providers and take corrective actions, if needed<br>- Provides input to frame agreements with service providers, if needed. | 50% | 1 |
| Global application owner | - Ensuring that the engineering tools provide the right functions and capabilities for new and existing products developed in R&D for efficient order engineering in all manufacturing locations<br>- Providing support for development and maintenance of common engineering tools<br>- Supporting new product development and product transfers | 50% | 1 |

As seen from Table 9, the responsibilities of Development group's participants cover a complete range of process development from the proposal of ideas to testing and implementation. The roles and responsibilities as seen from the table are distributed in a precise manner, with a strict hierarchy of responsibility. The official existence of the group is not documented and is not represented in the organizational structure of the company. In general, only members of the group and head managers are aware of the existence of this group.

The goal of Development group is to define good 3D working practices and document them to the internal knowledge database. Group's meetings are held monthly and the content of meetings is documented utilizing cloud-based technology for future distribution within key stakeholders. Based on a review of meetings' memos and prepared by Development group tables, development needs and ideas are discussed during meetings and prioritized by their urgency and importance. After that, the tasks are distributed among the participants, followed by discussion in a joint meeting, where the modeling rules / practices for the topic are presented and agreed. After the meeting, responsible persons document the agreed practices as a guide and submit it to Global Support, which transfers it to the internal knowledge database.

In Development group, a standard agenda of the meetings is a discussion about knowledge articles, open issues and issues that have been completed since the last meeting. Other than to Global support organization delegated tasks, such as creation of needed instructions, are exported to the departments' continuous improvement tables to achieve better transparency of the current development tasks. Again, due to the lack of key roles in terms of 3D software in Asynchronous machines department, the tasks are not exported to this department.

As seen from Table 9, at the moment the case company does not have resources, whose primary responsibility is process development or implementation of development tasks. For all participants this is an additional task, included in their official commitments. Table 9 represents the share of their time allocated to support and development activities, but their actual hours are not documented. The tasks are distributed without a specific schedule and therefore it is impossible to define the actual used time for implementation of the tasks. According to the information received during the interviews and review of the meetings' memos, currently, there are maximum four development tasks open at a time as a result of lack of resources. The list of prioritized development cases related to the current 3D engineering process is very long but new tasks will be taken only when the previous ones are closed.

### 3.4.2 3D Mechanical Engineering Practices

The current process of 3D engineering was mapped utilizing the results from the interviews, analysis of the internal documentation, the process mapping session and internal mapping practices of the case company. The 3D engineering process map is the first map that describes the 3D engineering process in the case company. A large number of product variations and types of components and models does not allow to produce a detailed map for each type of model. Therefore the produced map describes a most common process of modeling. The complete map can be found in Appendix 5. Due to the large size and complex technical terminology of the map, it was divided into main stages and presented stage by stage. Later, to simplify the description of the stages, they were grouped and presented as a linear process shown in Figure 3 below.


Figure 3. Simplified 3D engineering process in the case company.

As seen from Figure 3, a traditional 3D engineering process can be presented as an 8-step linear map. The process starts with the initial determination of the need for a model or other 3D entity. Next, before the modeling starts, a search is performed for any reference models that can be used as a template, thereby ensuring that the necessary part is missing in the PDM system. Subsequently, for the correct use of the software and modeling principles, the necessary instructions are reviewed, after which the modeling step begins. When the design is ready, the master data is filled in the PDM system. Later the ready item is checked by another engineer and then approved. A more detailed explanation of each step is presented next.

*Starting point* is the first step in the process. The need to create a new 3D entity arises in different situations, usually, in case of a unique design that differs from the standard or in the case of needed standard 3D model absence. The need may be a new product, a special component of the product, part of an assembly, manufacturing instruction etc. As was discussed previously, R&D department is responsible for product and component development, and initial design of machines. The department creates new components and other entities according to internal and global standards and the existing design of machines. Synchronous and Asynchronous engineering departments utilize created by

R&D department standard components and machine structures during mechanical engineering phase. Therefore, techniques and modeling methods applied by R&D department, directly affect mechanical engineering. Despite this direct dependence, the departments does not initially have cooperation in terms of the 3D engineering process:

> *Basically, the cooperation of these teams (R&D engineering teams) is limited by internal teamwork. In terms of our R&D engineering teams, maybe there is not too much cooperation with the mechanical engineering departments. (Global application owner, R&D)*

During the creation of new models and developing internal processes, R&D does not consult with mechanical engineering departments which leads to a misunderstanding regarding the 3D engineering process. As a result, design approaches used by R&D, does not always suit mechanical engineering needs:

> *The initial chain which supports mechanical engineering (R&D) in principle does not support us so much. Sometimes R&D does 3D design which is not suitable for our department. As a result some models we cannot to use as reference. (Senior mechanical designer, Asynchronous machines)*

In this case, the mechanical engineering departments are forced to update or create new models, which entails delays in the engineering process making it costly inefficient.

*Reference search* makes the second step in the process. The search for a reference can be performed in different ways, depending on the type of 3D entity being designed. Based on documentation review and interviews, the company does not have an accurate search method as well as clear practices of naming all types of components:

> *We have a lot of similar items in the system because it's difficult to find by name, etc. I cannot find the item if I do not know by what principle it is named. (Senior mechanical designer, Asynchronous machines)*

Due to the long history of the case company, during which multiple various software and databases were used, the search can be performed using several tools with different parameters. There are two main applications for reference search in which the search can be performed using various techniques. However, the search is performed based on the same database. It should be noted that in case of finding a reference, it can also be designed using 2D technology. In this case, the engineer will be forced to design a new 3D model, if schedule allows.

In addition to the search tools, the company has numbers of standards with listed item codes. However, based on a review of standards and interviews, most of these items do not have 3D models or the model is stored under a different ID number, which complicates the search.

*Instruction search* is the third step in the process. At the moment, the case company has a wide set of instructions related to the practices of 3D design. The instructions are in the process of constant updating and are part of the Development group meetings' agenda. Nevertheless, the company still does not have a complete list of instructions and there is a lack of process description.

As in the case of references, the 3D modeling instructions can be found from several places. There are two main places for instruction search, which are the engineering portals and the internal knowledge database. The knowledge database is relatively new, shared storage for different kind of instructions and standards, built utilizing cloud technologies. The instructions are categorized according to modeling solutions and are available for the whole case company. Additionally, all three departments have their engineering portals, developed independently from each other. The content of each engineering portal is generally available only for the department's engineers and thus, useful information presented in one department may not be available to another. The company also has a distribution of useful notes related to 3D engineering through email. Based on a review of mailings, initially the information was intended only for Synchronous machines and R&D departments. At the moment, the list also includes engineers from Asynchronous machines department. These notes in most cases stored in a separate database, which makes it difficult to classify them and search.

In case the necessary instructions are absent, the engineers can consult with colleagues or use the help of key- or super-users. Due to the lack of experience and awareness of Asynchronous machines department about the roles in the process, the engineers are often forced by trial and error to continue components' modeling as follows from the interviews and participant observations.

*Modeling* is the main and longest part of the process. Depending on designed product complexity it can last from several minutes to several days. According to interviews, basic 3D modeling is on good level in R&D and Synchronous machines departments and the amount of key- and super users' support sessions has significantly decreased compared to the situation two years earlier. At the same time, Asynchronous machines department suffers from a lack of experience even in the modeling of basic components.

Modeling can be divided into 3D modeling itself and in the most cases creation of a 2D drawing. After the component is designed, engineers create 2D drawing utilizing the same software, as can be seen from the process map in Appendix 5. Creating a 2D geometry utilizing 3D model increase the accuracy of the drawing and reduce the duration of drawing creation. Increased accuracy of 2D drawings is also seen as one of the main reasons for using 3D technologies.

The duration of modeling in some cases is reduced by utilizing the parametric modeling solutions. These solutions give the opportunity to create new models by changing dimension values of reference parametric model. Building of a parametric model is usually quite a complicated process, which requires deep knowledge of the product and systems and thus these models are related to C2 complexity level. In case of frequent needs for new variations of the component, the engineering time can be reduced dramatically. Despite the obvious advantages of this technology, the company practically does not have such models, which is due to the lack of skills and resources. Also, the existing parametric models are not listed or distributed throughout the company.

*Data filling* is the fifth step in the process. After the design is ready, the master data must be filled in the PDM system. This step can be seen as a sub process of modeling due to the need for subsequent updating of the drawing datasheet with updated data. As it was said earlier in this sub-section, the company does not have a clear practices of naming all types of components. Absolutely the same situation with the other types of data to be filled at this step. Some attributes have a specific list of variants that can be used, type designation for example. At the same time, additional information related to the description of the special qualities of the component can be filled in any form or not filled at all.

As seen from the process map in Appendix 5, during the process of data filling, the actions are performed in two applications with the transition from one program to another and back. In theory, all needed information can be filled in the 3D software. The case company has already created a development idea and impulse to Global Support organization related to this improvement.

*Checking, approving and finish* make the last steps in the process. After all the steps are performed, at least one engineer should check the ready item. Currently, the company does not have specified roles for checking. Therefore engineers can ask for checking from any sufficiently experienced engineer. Also, there is an absence of clearly defined guideline of what data and how the item should be checked. As a result, in most cases for example 3D design approach and existence of identical items are not checked.

After the item is checked and necessary updates or corrections are made, the item is approved in PDM system with the subsequent appearing of data in ERP system for further usage by production planning and purchasing if needed. The designed and approved item may be used in the structure of the product or utilized in different assemblies or drawings etc. Basically the process stops at this stage. Subsequently, the created item ID is not entered in any list or library except for the components stored in the standards' database. The finding of this component later is extremely complicated as a result of the lack of standards for naming and data filling also.

These eight steps display the full current 3D mechanical engineering process of the case organization. Next, S&Ws in this process are discussed.

## 3.5 Analysis of the Strengths and Weaknesses of the Current 3D Process and Development Practices

During Data 1 round, many strengths and weaknesses were identified regarding the current 3D mechanical engineering and development practices in the case company. The findings were collected, grouped into six categories and illustrated utilizing fishbone diagram techniques. The strengths and weaknesses of the current 3D engineering process are presented in Figure 4 below.

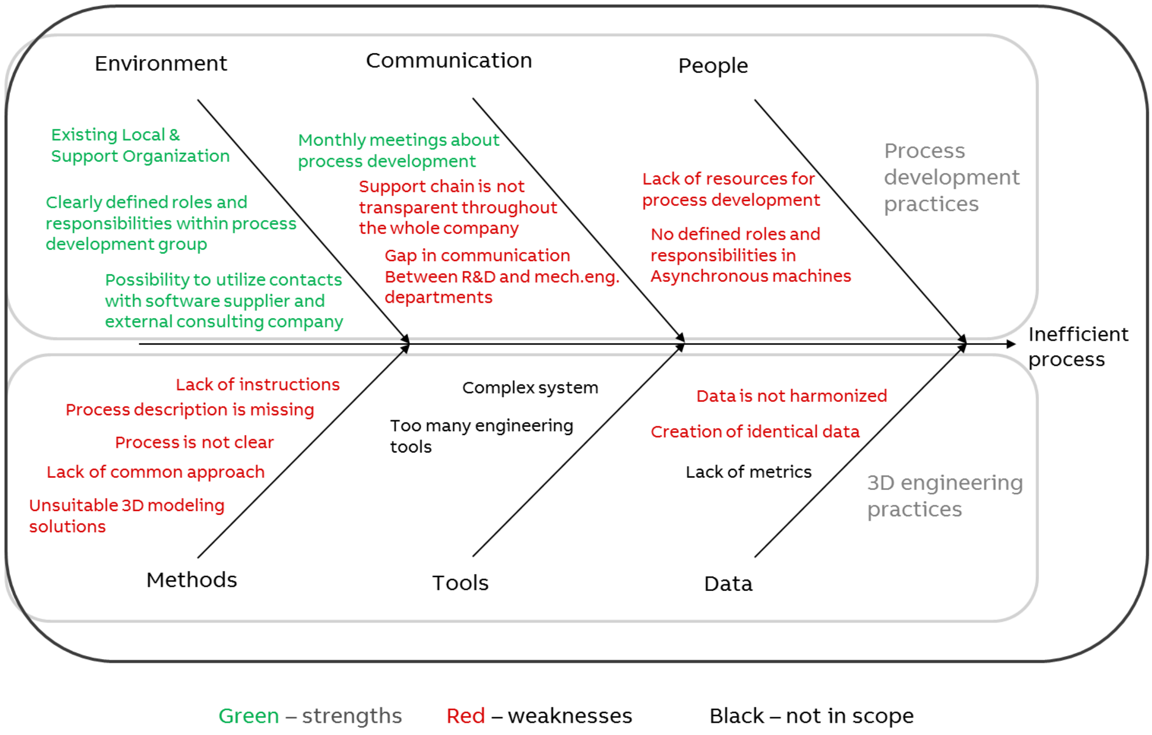



Figure 4. Strengths and weaknesses of the current 3D engineering process and root causes.

As seen from Figure 4, the findings include a considerable number of weaknesses and only a few strengths. The diagram shows the distribution of the main categories of the findings. The top categories of the diagram cover the findings related to the process development practices or the prerequisites for the effective operation of the process. All categories mutually interact with each other through common core, affecting the overall flow of the process. For example resource problems directly affect communication, which in the same manner affects the environment. As a consequence, despite the strong environment, the process cannot be developed efficiently, being reflected directly on the 3D engineering practices, which represent the lower categories of the diagram.

As seen from Figure 4, most of the weaknesses refer specifically to the 3D engineering practices. There is the same tendency in the interaction between findings, that is, the two-way dependence of the categories on each other, the methods of the 3D engineering practices cannot be effectively utilized without the prerequisites from the data, and tools even if they would be improved. In the same way, the data cannot be harmonized without defined methods and tools. The detailed description of each finding is discussed next.

### 3.5.1 Strengths

As Figure 4 shows, almost all strengths refer to *the Environment* and only one to *Communication* categories. Indeed, as was discussed earlier in Sub-sections 3.2 and 3.4.1, the case company has a well-defined support organization with named key-, super-users and application owners. The structure of the organization is clear and there is close communication between the key stakeholders in the case company. Additionally, the organization utilizes direct contacts with software supplier and external consulting company, which have wide experience and knowledge in the field of technical development of 3D practices. Therefore, the company has very useful and necessary support, thereby improving its internal knowledge in this field. Improving of internal knowledge in terms of 3D technologies is also extremely important due to the high potential and wide spread of the technology.

Also, the Support organization already making the first steps in the 3D engineering process development by utilizing established process Development group. The group, mainly consisting of key stakeholders of the Support organization, creates good prerequisites for the effective development of the process. The roles and responsibilities within the group are distributed in efficient way. Development ideas and needs are prioritized according to urgency and roles for implementation defined for each new task. At the same time, monthly conducted meetings with documenting of solved issues, tasks under implementation and overview of upcoming software releases allow to improve communication within the company, which, along with the collaboration, is not at a sufficient level, as discussed next.

### 3.5.2 Weaknesses

Based on the results of the analysis, the illustrated fishbone seen in Figure 4 presents two types of weaknesses. This study focuses on the weaknesses marked in red. The weaknesses marked in black either refer to another project of the company or their consideration requires a deeper and separate analysis. Nevertheless, these weaknesses are taken into account during the recommendations for further development in Section 7.

As seen from Figure 4, there are two defined weaknesses related to *Communication.* Following the results obtained during the CSA, was revealed that the *Support organization is not transparent to all stakeholders*. In the case company, not all engineers are sufficiently aware of its existence. During participant observations and conversations with engineers in Asynchronous machines engineering department, it became obvious that the absolute majority does not have information about 3D key- or super-users and their responsibilities in the process. The company also does not have a support structure with a description of roles and responsibility areas available for all users. As a result, during difficult situations search for support can take a long time, which negatively affects engineering processes, making them cost-ineffective. At the same time, there is a risk of incorrect or illogic use of the software by less experienced engineers due to inaccessibility of support.

In the case company, there is also a *gap in communication between R&D and mechanical engineering departments*. The initial lack of collaboration and cooperation in terms of 3D modeling compromises the effectiveness of the engineering work carried out in the mechanical engineering departments. Insufficient familiarization with the principles of used 3D models by different departments entails misunderstanding. This gap in communication between the departments has negative effect on almost all areas of the process, visible for example in the creation of identical data and unsuitable 3D modeling solutions.

Several weaknesses in terms of resources (see *People*) were revealed which also directly affect cooperation. Both, Synchronous and Asynchronous mechanical engineering departments perform similar tasks with regard to engineering, differing only in the type of products. Despite the relatively small use of 3D technology, at the moment at least seven engineers are forced to use 3D in some way in Asynchronous machines department. At the same time, in Synchronous machines and R&D departments all engineers use the software and 100% of new products designed nowadays in 3D. Due to a *lack of 3D CAD key- or super-user positions in Asynchronous machines* mechanical engineering department, representatives of the department do not participate in Development group. Thus, the cooperation with other departments is practically absent in terms of the 3D engineering process. As a result, the engineers of the department cannot influence decision making or take part in the development of the process. Therefore, internal processes and features of this department are not taken into account putting at risk the effective development of the 3D engineering process.

In addition, the development of the process also suffers from a *lack of resources for implementing development tasks*. Basically, the company has named key- and super users who are responsible for instruction and process description writing, and staff training but their time is not sufficiently resourced for implementing these tasks as follows from the review of documentation and interviews:

> *In fact, not enough resources that would develop the process. Instructions, process descriptions etc. are still very much not done. Everyone just does something for what there is time. (Super-user, Synchronous machines)*
>
> *It is good that they have been defined (Roles). But in reality their hours are not resourced. They do not have a time for completing development tasks. Focus is on giving support but not on development. (Global application owner, R&D)*

As seen from the comments above, the main task of the responsible persons is mechanical engineering. For performing development tasks they are forced to look for free time between engineering projects. As a result, such use of resources makes the process of development slow and inefficient.

Next, as seen from Figure 4, the absolute majority of weaknesses refers to *Methods.* First of all, there is a *lack of a complete list of instructions*. The situation is complicated mainly by three main factors. First, as was discussed previously, insufficient resources for process development and therefore for creating of instructions. The second factor is a large number of product variations and design approaches. Creating of separate instructions for each design is a laborious and long process. The absence of a defined and described common approach makes it practically impossible to write instructions that would cover all possible approaches. This factor also seen as one of the weaknesses and is discussed later. The third factor relates to communication. Due to the lack of transparency of the support chain in the company, many engineers do not even know about the existence of needed instruction. In particular, Asynchronous machines engineering department is not informed about the creation of new instructions and therefore does not actually use them. As a result, there is no feedback related to the existing and needed instructions from Asynchronous machines.

The new software was introduced as a necessary action. The manufacturer announced the termination of old software's technical support. Due to the urgent need to optimize the operation of the system with the new software, the general rules of working with the new software were not specified. The new software has many functions and gives a large number of design options. *The lack of common approach* affects the quality of engineering work, components' updating time and as a result the workflow becomes inefficient.

This situation is complicated by a *lack of basic process descriptions, process maps and description of organization structure* in terms of the 3D engineering process. The current process has no description which makes it difficult for new employees and less experienced engineers to start using the software. Basically, they are forced through trial and errors to seek solutions to various problems. It takes a lot of time and modeling solution does not always correct and as a result the model is not suitable for future using as a reference.

Weakness areas related to tools, such as *complexity of the system* and *a large number of engineering tools,* complicate the process by forcing designers to move from one tool to another, not allowing to focus on the performing task. Different programs allow to perform a wide range of tasks, but at the same time making the process more difficult, especially for new employees.

Finally, the lack of common approach, cooperation and resources lead to one of the most invisible but significant problems, *lack of data harmonization and creation of identical data*. Historically, engineers are quite independent in terms of data creating. Additional items, drawings, 3D models of basic components, assemblies of final products are necessary parts of engineering work. Each created item remains in the system forming a mass of data. The engineers create new data when needed data cannot be found. Due to a lack of common standards the search attributes, type and name of identical components may differ. That leads to the *creation of several copies of identical data* in the PDM system. The data is later used in different assemblies/structures which makes it extremely difficult to update or change components, since this will affect all places where the component was used.

This endless creation of identical data is a wasted time that does not add any value to the product and complicates the operation of the system. The process of data creating is not regulated by anyone. Although the process of data approving in the system includes the checking of the items by 1-2 engineers, the 3D modeling approach, existence of identical items, naming and storage of data in most cases are not checked. Also, the absence of standard items' 3D models, metrics, and lack of standard item libraries and

3D assemblies of standard products complicates the work of engineers and increase engineering leading time.

## 3.6 3D Engineering Practices in the Another Company of the Case Organization

As discussed previously in Sub-section 3.2, the Global Support organization supports all BU's production units which use PDM and CAD systems, including 3D systems. Based on information gathered from interviews with Global application manager and Global application owner, the differences between different organization's companies are quite huge in terms of modeling processes. Additionally, each factory is absolutely responsible for own local processes, which makes data collection among all companies a long and time-consuming process. Nevertheless, 85% of the respondents mentioned during interviews and advised to contact a certain company that belongs to another production group but uses the same PDM and CAD systems. According to the information received in the analysis, the second company was able to achieve much greater progress in terms of 3D engineering process, than the case company. To familiarize with the practices of these company, it was visited and a meeting was held with one of key stakeholders directly involved in the development and improvement of the process.

Initially, it is important to note that the ability of another company of the case organization to develop the process and systems is much simpler than in the case company. Because the factory is practically separate and belongs to the global environment only partially, it can make decisions much more quickly and not affect global processes. Also the products and internal standards of the departments are significantly different from each other, so later described practices cannot be used directly in the case company. Nevertheless, the overall picture of the process can be comparable. To facilitate comparison and future decision-making, the findings are discussed according to the categories presented in Figure 4: environment, communication, people and methods, tools, and data.

*Environment*, as shown on the basis of the interview, is developed and maintained quite effectively. The software was introduced for the company under the same circumstances as in the case company, that is, urgently and as necessary action. Similarly with the case company, the factory created internal process development group, consisted of key stakeholders from different parts of the company. Development of the process was started from the most important things and then went to smaller sub-topics. The group also included a representative of an external consulting company due to its extensive and rich experience in the field of 3D technology and process development. At the moment the consulting company is still actively involved in the development and support of the process. For example, the company has a permanent consultant, whose task is to create complex parametric assemblies for automation of engineering processes.

*Communication,* based on the information received, is at the desired level. The interesting finding here is a former similar problem with communication between R&D and other departments. The structure of these company is relatively the same in comparison with the case company, so the unit also has a R&D department, who defines a standard structure of the products. Mutual understanding in the 3D process was not achieved initially, which influenced the quality of the performed work. Later the communication was improved through key users in different parts of the company. Their task was to convey information about common 3D engineering practices and explain the reasons for such use of the software. In this way, a dialogue was achieved between users from different departments that, for example, helped to achieve mutual understanding in the sense of the applied modeling techniques.

*Resources* were determined according to the need. It should be noted that the main part of the Development group consists of actual software users, that is, engineers. The time for performing development tasks was also resourced for each member of the process individually, together with heads of departments. According to the Informant 6: “People must be reserved for doing things. The process does not come by itself. It takes time and action.”

*Data and tools* are one of the areas on which the unit has concentrated particular attention. The company has made a considerable job in terms of data harmonization, creating new models originally designed correctly, removing old ones and creating component libraries. At the moment, according to the Informant 6 (Data 1), the company have 98% of data harmonized that along with the invention of special built-in library applications helps conveniently use the standard items which helps to perform engineering work more effectively.

*Methods* are seen as one of the strongest sides of the company. The company does not have a description of the 3D process as such, but has a large number of common instructions that are suitable for using by different departments. 3D engineering made in accordance with the generally accepted rules and techniques, which are also verified during checking. The process of data creation and control requires special attention. Certain engineers are responsible for creating certain standard or complex models. Some types of 3D models are tested to use the correct modeling techniques. All this affects the quality and quantity of created data.

Collected during the interviews information, along with detailed analysis of the weaknesses and strengths of the case company, allows seeing the difference in processes. The next sub-section summarizes the key findings of the current state analysis.

## 3.7 Key Findings from the Current State Analysis

After the individual strengths and weaknesses were analyzed and categorized according their specificity, they were summarized into categories, forming key findings. The key findings are presented in Figure 5.

**SUMMARY OF STRENGTHS**

**Availability of local and global support**

- Existing Local & Global Support Organization with possibility to impulse development ideas related to PDM & CAD (3D)
- The possibility to utilize contacts with software supplier and external consulting company

**Established development working group**

- Monthly meetings about process development and upcoming software releases
- Clearly defined roles and responsibilities within the group

**SUMMARY OF WEAKNESSES**

**Inefficient distribution of roles and responsibilities**

- Lack of resources for implementation of development tasks
- No defined roles and responsibilities in Asynchronous machines

**Lack of defined 3D engineering workflow**

- Lack of common approach
- Process is not clear and description is missing
- Unsuitable modeling solutions and creation of identical data

**Lack of collaboration and communication**

- The Induction machines is not included in the development group and thus is not informed about development ideas and can not influence decisions
- Gap in communication between R&D and mechanical engineering departments
- Support chain is not transparent throughout the whole company

Figure 5. Strengths and weaknesses of the current 3D engineering process.

As seen from Figure 5, there are two key strengths and three key weaknesses in terms of the current 3D engineering process. The first key strength is *availability of local and global support in the case company*. The support is available through web-based, intranet platform and supporting staff. There is an opportunity to impulse development ideas related to PDM and also CAD systems and utilize more contacts with the 3D software supplier and consulting company. Consulting with Support organization during the decision making processes positively affects the environment, which also affects communication through second key strength, *established development working group.* Attempts to develop the process through the working group have a positive impact on the improving experience of employees and internal knowledge of the company. According to all respondents, the process is currently working much better than a year after the software introduction. The development continues but not so effectively that gradually leads to key weaknesses.

The first key weakness is the *inefficient distribution of resources* in terms of 3D engineering process development. Lack of resources and allocated time for implementation of development tasks is an obstacle on the way to an effective process. Also, the absence of defined roles and responsibilities in Asynchronous machines engineering department has a negative impact on the user-support, affecting the quality of work and communication.

The second key weakness is a *lack of defined workflow*. Currently, there is a lack of instructions, process descriptions and common approach. These shortcomings have direct effect on quality of performed engineering work, seen in unsuitable modeling solutions and data quality and amount.

The last key weakness is *lack of collaboration and communication*. This weakness include unawareness of Asynchronous machines department about development cases, ideas and decisions, gap in communication between departments and non-transparent support chain. All these shortcomings have a direct impact on operational activities of the company compromising the principles of effective work.

As can be seen from the key findings, the main strength area of the process is the *Environment.* However, due to the lack of resources and communication, this strength cannot be fully utilized. From the technical part of the process, most of the weaknesses are related to the *Methods*, which *per se* does not provide the prerequisites for an efficient process. As the current state analysis ends with the most important findings, the thesis continues to the literature review that focuses on finding best practice, ideas and solutions for the selected weaknesses.

# 4 Best Practice of Engineering Process Development

This section overviews the theoretical background of engineering process development. Due to the wide availability of techniques, variations, and theories related to the theme, the section discusses topics of the existing knowledge, which relate to the main findings of the CSA. The section includes discussion on the main theories and methods of process development and subsequently covers specific areas of literature, such as process workflow, process roles and responsibilities, collaboration and effective communication in organizations. The linkage between these areas and critical weaknesses of the original process can be observed in Sections 3 & 4.

## 4.1 Approaches to Mechanical Engineering Process Development

Mechanical engineering is a diverse field that encompasses a vast number of practices, principles, standards, innovations in the development of mechanical systems. Engineering covers the possibilities of solving problems that provide and optimize safe, sustainable solutions for the design, manufacturing, and operation of machines, devices, tools, etc. (Imeche.org, 2018.) In this process, the mechanical engineering companies, departments and teams work closely with other environment's participants while performing specific tasks to solve customer's problems (Ullman and David 2010: 67-68). In other words, the practical process of mechanical engineering is a set of completed tasks for the established goal as a result of clearly defined and correct prerequisites provided by all the parties involved.

According to Sharp and McDermott (2009), a business process is "a collection of interrelated activities, initiated in response to a triggering event, which achieves a specific, discrete result for the customer and other stakeholders of the process" (Sharp and McDermott 2009: 56). Therefore, mechanical engineering can be considered as a business process. Thus, in the development of engineering processes, the same practices and canons can be utilized as in the development of other business processes, depending on the process's type and nature of the environment.

Due to continuous pressure from evolving market demands, global competition and need for innovation engineering processes forced to be improved utilizing emerging and existing technical solutions (Khan et al. 2013: 1-2). As a result, changing environment, activities, tools, and products may create many problems with the processes. The problems may arise if something new is done and there is no process as such, process is not followed, or the process is not good enough to perform the tasks. (Martinsuo and Blomqvist 2010: 4-5; Blomqvist 2017.) There are different solutions and tools used to eliminate different types of problems. The decision on the process development approach is of critical importance before going any forward. The development of a process involves many methods, but in case a company does not abandon or outsource the process, there are only two possible courses of action which are "improve" or "redesign". (Sharp and McDermott 2009: 320).

For the last several decades, various approaches of how to develop processes have emerged (Martinsuo and Blomqvist 2010: 4-5). The most popular and used by many large enterprises approaches are Business Process Re-engineering (BPR), Total Quality Management (TQM) and Six Sigma. The core of the BPR theory lies in a radical restructuring of business processes to achieve the established goal. TQM approach focuses more on a continuous process of development, taking into account more broadly internal or external customers' expectations. Six Sigma is a set of methods and practices, the purpose of which is, as well as TQM, to systematically improve the process. In contrast to the TQM, Six Sigma more carefully emphasizes the individual stages of the process, mainly focusing on the quality of the output. (Davenport 2005: 1-2; O'Neill and Sohal 1999: 571-576; Smart, Maddern and Maull 2009: 491-498; Sharp and McDermott 2009: 6.) The main characteristics and differences of these three approaches can be seen from Table 10.

Table 10. Comparison of BPR, TQM and Six Sigma characteristics (created from: Davenport 2005: 1-2; O'Neill and Sohal 1999: 571-576; Smart, Maddern and Maull 2009: 491-498; Sharp and McDermott 2009: 6).

| **Characterictic** | **Business process re-engineering** | **Business process continuous improvement** | |
|---|---|---|---|
| | | **TQM** | **Six Sigma** |
| Level of change | Radical Redesign and innovation | Incremental change and improvement | Alighting and maintaining |
| Deployment | Top-Down | Bottom-Up | Top-Middle-Down |
| Type of change | Cultural and structural | Cultural | Cultural |
| Goal | Streamlining | Small-scale improvements | Alighting |
| Relative risk | High | Low | Low |
| Tools | Process maps | Statistical control | Statistical control |
| Scope | Cross-functional | Narrow | All-embracing |

As seen from Table 10, the approaches offer different practices of how to improve/re-engineer the process. Nevertheless, despite the initially different cores of re-engineering and continuous improving approaches, they can co-exist in the same environment interacting with each other and strengthening their practices. Moreover, O'Neill and Sohal (1999) emphasize that for example, BPR is less likely to succeed outside Total Quality Management approach because it uses TQM methods, processes, and customer orientation to provide additional parameters. If the process is developed on a one-time basis, without the training, experience and organizational infrastructure used in TQM, it can be expected that the organizational resistance will be greater than in the culture where the planned and continuous quality changes are used. (O'Neill and Sohal 1999: 576.) Sharp and McDermott (2009) are also argued that the process re-engineering and continuous improvement had merged and are not separate approaches anymore. As O'Neill and Sohal (1999) noted, many authors suggest that the company can succeed in the case of using process re-engineering techniques if they do not undermine the foundations of continuous improvement. Some authors at the same time argue that both types of approaches can be used in the same company at different periods of time for achieving desired levels of performance improvement. (O'Neill and Sohal 1999: 576.)

As a result of this discussion, it can be concluded that there is no right answer of what set and balance of tools, parameters, and techniques can guarantee an optimal development of a process for a company. Processes, as well as companies, differ in nature, type and scope. Nevertheless, as seen from Table 10, all three described earlier approaches include cultural change as one of the characteristics. Organizational culture framework, developed by Quinn and Rohrbaugh (1983) was repeatedly used to study the interrelationship of organizational culture and various approaches for process development. Figure 6 below shows effectiveness of approaches depending on the culture of the organization.

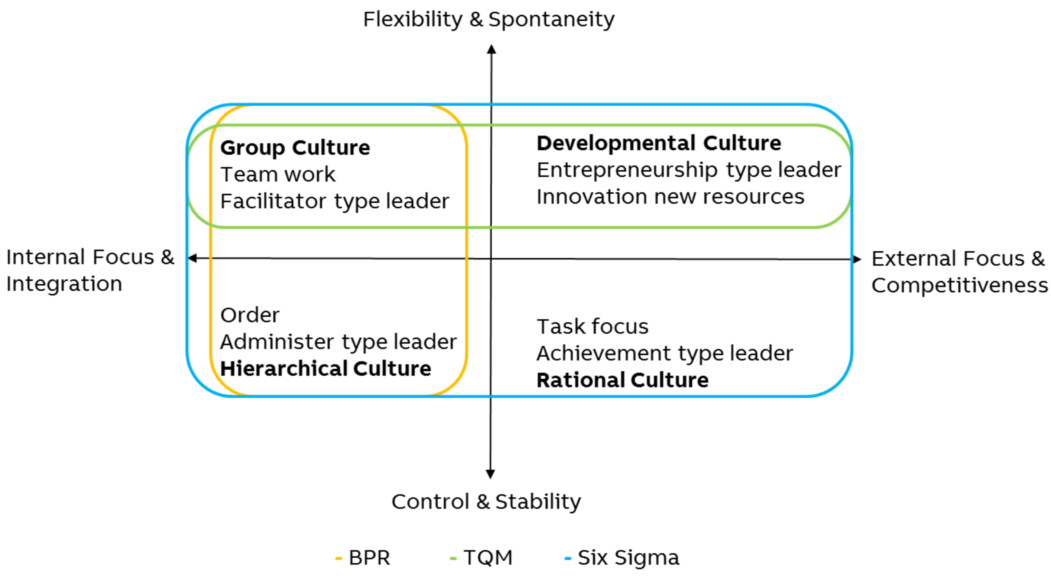



Figure 6. Effectiveness of approaches depending on the culture of the organization (adapted from Quinn and Rohrbaugh, 1983; Kappos and Croteau, 2002; Maroofi, Nazaripour and Maaznezhad, 2012; Gimenez-Espin, Jiménez-Jiménez and Martínez-Costa, 2013).

As seen from Figure 6, all three mentioned earlier approaches are effective in case of group culture. Referring to the possibility of methods' merging it looks like in the case of a group culture presence, all three approaches can be efficiently used by an organization without incurring contradictions during process development. Additionally, the culture of any company is heterogeneous in its nature. Therefore, the company may use different elements of different types of culture, creating a unique organizational environment. Consequently, it seems like a company that focuses on teamwork and innovation supporting, while at the same time reasonably allocates resources and defines roles and responsibilities to maintain control and stability, has an excellent opportunity to efficiently and correctly rebuild its processes and support their continuous improvement. Summarizing the above arguments, it can be concluded that depending on the type of process, organization and the desired result, a company, developing a new process or improving the existing process, can utilize various tools, scope, and resources and succeed in case of focusing on flexibility, internal and external customer, continuous development and teamwork.

Summing up, a business process includes a set of interdependent activities established to perform a specific task. Therefore, defining the process workflow, or sequence of activities, is of critical importance for improving organizational performance. The necessary practices for determining the efficient workflow are discussed next.

## 4.2 Defining the Process Workflow

Every process in a company has its specific purpose, its place in the organizational hierarchy, the ultimate goal and affects the overall system in its own way (Sharp and McDermott 2009: 56). Different approaches to process development are always in one way or another focused on the customer. A clear vision of who is the key customer in a particular process is crucial in determining the workflow. (Martinsuo and Blomqvist 2010: 5, 11.)

There are two types of customers, which are internal or external. External customers more often are customers who buy company's products or services or end users. Internal customers are employees, teams or other stakeholders that interact within the company as a regular part of their roles and responsibilities. Since the external customer plays the most significant role in the meaning of the business, the processes in which these customers are directly involved are called core or operational processes. Most companies have 5-7 core processes, which are for example customer process, including customer acquisition or service process, including service development and delivery, etc. (Sharp and McDermott 2009: 57-60). At the same time, engineering processes of the company can be listed into several core processes. For example, the development of a new product under the product process and order engineering under delivery process. Defining of core processes play a significant role before process modeling stage, as in the matrix organizations, the process may require resources from all departments of the company (Martinsuo and Blomqvist 2010: 6).

Core processes are served by supporting processes, such as technology, HR, finance support (Bitici et al. 2011: 3). Core and supporting processes, in turn, consist of the main processes that can be divided into several vertical or horizontal sub-processes depending on the organizational structure. Since supporting processes almost always serve internal customers and core processes serve external customers, the importance of customer orientation is seen throughout the entire process hierarchy. (Martinsuo and Blomqvist 2010: 6; Sharp and McDermott 2009: 60-61.) For example, in the case of an inefficient servicing of an internal customer, there is direct effect on the whole chain of the core process, which in turn can affect the satisfaction of the external customer or the end user.

As noted by Bitici et al. (2011), in addition to the supporting and core processes, there is a third important type of processes, which is managerial. Managerial processes serve core and support processes. But while core and supporting processes are responsible for present performance, managerial processes sustain long-term performance by setting direction, monitoring, and control. Bitici et al. defined five types of managerial processes, which are managing performance, decisions making, communications, culture, and change. (Bitici et al. 2011: 853-854.) Their interconnectedness will be discussed later in Sub-section 4.4.

Sharp and McDermott (2009) look at the concept of process from the point of views of enablers and drives. According to this concept, any business process has enablers, which “enable” process to perform efficiently. Therefore, the process will never perform optimally until all enablers provide the prerequisites, including effective interaction with each other. There are six identified enablers which are the workflow design, information systems, motivation and measurement, human resource, policies and rules, and facilities. Additionally, according to the concept, business processes support the organization’s strategy, objectives, and mission. They in the same time drive business processes in a correct direction. (Sharp and McDermott 2009: 69-71.) Combining the two concepts presented by Bitici et al. (2011) and Sharp and Mcdermott (2009) some common features can be observed. The combination of the concepts is illustrated in Figure 7 below.

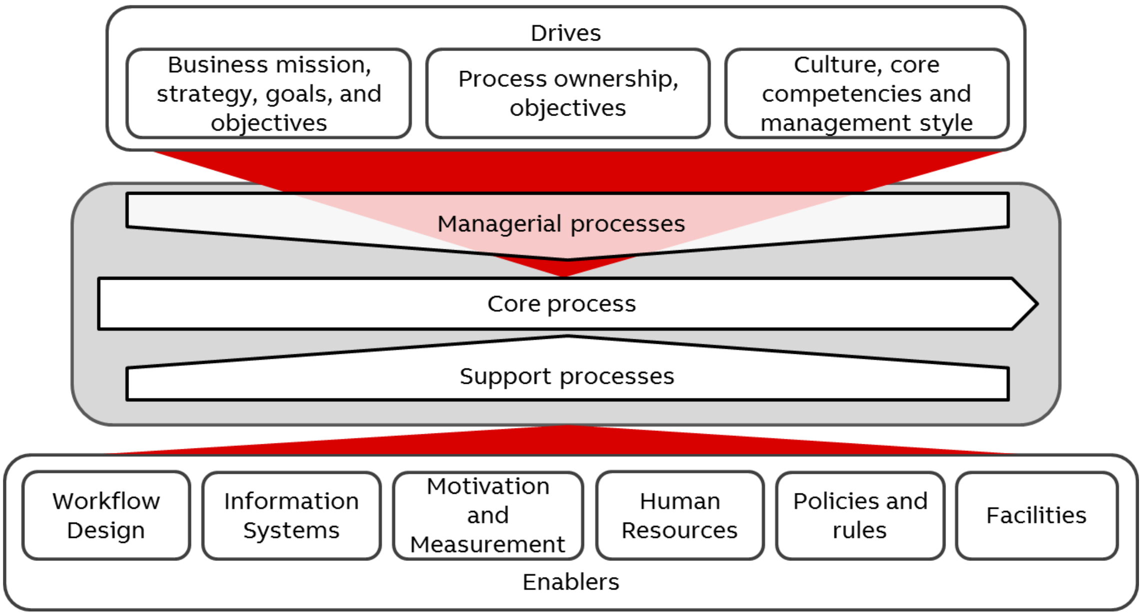



Figure 7. Interconnection of processes in context with drives and enablers (adapted from Sharp and McDermott, 2009; Bitici et al., 2011).

As seen from Figure 7, while enablers support a whole system, process drives interact with the system through managerial processes. This makes processes' interaction chain longer, increasing the number of variables. As a result, in the case of the need to develop core or supporting processes, it is also necessary to take into account the characteristics and condition of managerial processes and make sure they comply with business mission, objectives, and culture.

Before making process improvements, the current state and maturity of a process need to be defined. There are several practices of how to evaluate the condition of business processes, including checking of process maturity and enterprise capability. PEMM (The Process and Enterprise Maturity Model) framework, presented by Hammer (2007) is a handy tool for assessing the maturity of individual processes, regardless of their type. The tool also helps to evaluate capabilities of the company, which is also a particularly important aspect during setting of process's characteristics. Defining of the process's characteristics, including setting of goals, requires explicit recognition of the company's capabilities and maturity of processes that are in the hierarchy at a position higher than the process being developed. In the case of insufficient maturity of core, managerial or support processes established high requirements just cannot be fulfilled that affect the overall performance of the company (Hammer 2007: 113-119.) However, PEMM framework is not in itself a road to the successful development of the process. This model offers the necessary prerequisites for successful defining of process characteristics and workflow modeling.

Once the company has identified the key processes and evaluated the prerequisites from the process system side, the next step in defining the workflow is to determine process characteristics (Sharp and McDermott 2009: 323). Process characteristics can be described using a process matrix, or described in writing as a standard document. Regardless of the technique for describing the characteristics of the process, there are necessary rules for their definition and evaluation before modeling of the workflow can be started. First of all, the influence of each proposed characteristic is evaluated in the context of each of six enablers to persuade the absence of negative impact on them (Sharp and McDermott 2009: 325). Second, process's objectives and goals are established both, short-term and long-term and third, they are interconnected with company's strategy to avoid possible conflict within the organizational objectives (Martinsuo and Blomqvist 2010: 7, 23; Hammer and Stanton 1999: 117; Sharp and McDermott 2009: 72).

When the main chain of activities and the hierarchy of processes is transparent, the company's capabilities and process characteristics are defined, the process can be mapped utilizing different approaches, such as task matrix, flowchart, diagram or textual instruction. Regardless of method the primary target of process mapping or modeling is to map the entire process, which starts and ends with the customer, for determining what steps need to be taken, and what tools and systems need to be used to fulfill internal or external customer expectations. (Martinsuo and Blomqvist 2010: 14, 19.)

Sharp and McDermott (2009) advise modeling an “ideal” process regardless of internal or external constraints, which will subsequently be revised in accordance with the conditions of the real environment. The “ideal” picture can create a perfect model that can be a target for aspiration. (Sharp and McDermott 2009: 340). In case the process needs to be developed for several departments, the ideal process can be considered regarding standardization of the process. The process standardization topic is touched upon in many process development literature. Since the 90s, there has been an opinion in the literature that it is necessary to standardize as many processes as possible if this does not contradict various needs of the customer. Indeed, this approach offers many benefits. Standardization can facilitate the exchange of information on how the business operates, provide a smooth transition between the boundaries of the process, increasing the flexibility and plasticity of the organization. (Hammer and Stanton 1999: 114; Davenport 2005: 100-101.) Therefore, the approach can also has a positive effect on the efficiency of the development of the process.

But as practical experience shows, not all processes work in the most efficient way if they are standardized. The need for standardization or diversification can be assessed using a simple rule described by Hall and Johnson (2009). According to their theory, in the case of low variability of the process environment and a positive value of output variation to the customer, standardization can positively affect the workflow. Accordingly, if the environment has a high output variability, the diversification of process is more favorable for the organization. In this situation, it becomes essential for the company to invest in providing employees with skills, judgments, and cultural assessments in order to succeed in variable conditions. (Hall and Johnson, 2009). This can be achieved through methods of the continuous improvement described earlier in Sub-section 4.1.

Summing up, effective development and support of the process require a high level of communication and collaboration that cannot be achieved without clearly defining roles and responsibilities for specific tasks. Next, the popular techniques and theories of defining roles and responsibilities will be discussed.

## 4.3 Setting the Process Roles and Responsibilities

The development of processes important to the effectiveness of the company includes detailed modeling of the workflow with the allocation of necessary resources for efficient performing of the tasks (Sharp and McDermott 2009: 56). This is especially important in matrix organizations with multi-tasking processes, where, as was mentioned earlier, resources may be needed from several departments. Resources do not always mean a person. A resource can also be a whole company, an information system, a department or a team. (Martinsuo and Blomqvist 2010: 6.) Regardless of the type of resource, transparency of its role and a clear description of responsibility are necessary prerequisites for an effective performing of the work. As actual performers of the process's tasks can also be internal customers of the company, the definition of their roles and responsibilities and adequate allocation of resources is also an integral part of the development process.

Since the re-engineering and continuous improvement of the process itself require resources, identifying of key stakeholders is one of the first steps to the proper allocation of resources. In some cases external suppliers can be used to develop the process, but usually, the use of internal resources is more efficient. The use of external resources requires money investments and their supply is always limited. Using internal stakeholders helps to better understand the process from the internal customer's point of view, also developing organizational knowledge. (Martinsuo and Blomqvist 2010: 6.) Many authors of BPR literature, recommend the availability of such resources as senior manager, steering group, process owner, team leader and redesign team during the process re-engineering, followed by the elimination of groups and the dispersal of roles among employees. In the case of the urgent need to develop a process in a matrix organization, this can affect the work processes quite dramatically, affecting the overlapping of roles and responsibilities, and a lack of understanding of the new environment. (O'Neill and Sohal 1999: 578-579.) By combining both, process re-engineering and continuous improvement approaches, the initial distribution of roles and responsibilities among actual performers with a focus on continuous improvement and process support by established process teams look more favorable.

Key stakeholders, as well as other types of resources, can be identified during the process mapping. Described workflow allows defining process customers and performers. The definition of the necessary roles for performing the various process's activities is the first step towards determining the needed resources. They help to present the workflow in a more detailed format. (Bijwaard et al.: 2000: 3.) One of the many techniques for defining and efficient allocating of resources is the classification of resources. The classification can be followed by the definition of process groups and owners. This also allows to increase the efficiency of supporting and managerial processes.

In particular, the classification of resources plays a significant role in the organization, where the process is developed for several units, departments or groups. In this case, there is a need for coexistence of vertical and horizontal process structures in the context of partnership. One of the most convenient and popular techniques for resource classification is Petri Nets (PN). PN is a graphical and mathematical modeling and simulation tool utilized in project management. The classification of resources based on the PN principle is simple and efficient. This technique allows classifying roles on the basis of different tasks both in the context of one department or group, and the whole organization, including individual organizational units. Figure 8 below represents resource specification for performing four user tasks in the context of one organizational unit. (Aalst 1998: 21-22, 48-49.)

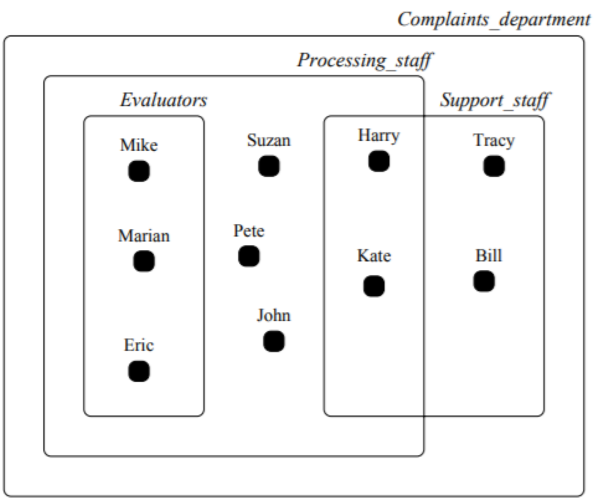



Figure 8. Resource specification utilizing Petri Nets principle (Aalst, 1998: 28).

As seen from Figure 8, there are several roles in one unit, clearly marked on a simple map. As seen, resources combined into groups can have a different level of responsibility. So, for example, support staff is formed by two specifically identified persons and two combined, which also have a second role. Thus, the work of the support staff includes direct interaction with the process personnel. If necessary, the combined roles can consist of a larger number of roles (Aalst 1998: 46). An example of a combination of roles and processes in the context of various organizational units can be seen from Figure 9 below.

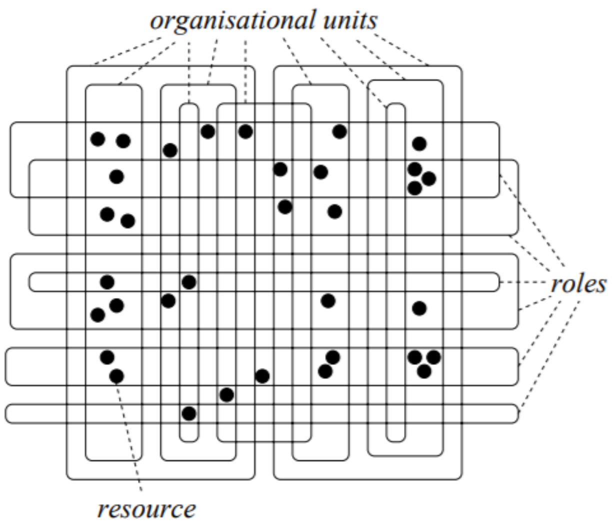



Figure 9. Resource classification in the context of various organizational units. (Aalst, 1998: 29).

As shown in Figure 9, the roles include resources from several units. Thus, the number of resources allowed to perform the tasks can be reduced, while simultaneously achieving a balance between the distribution of roles among units, control under the process and improving communication (Aalst 1998: 50). Despite the intersection of roles, the organization becomes more plastic as a result of simultaneous monitoring of certain areas of responsibility by several players. Additionally, improved communication can allow the use of both formal and informal types of communication.

Despite the obvious advantages of this method of resource allocation, the question arises of how to manage the created groups. To coordinate them, companies usually define responsible persons, described by different authors as process owners or managers. These responsible persons are seen as champions of the process, having real responsibility and authority over making decisions about control and continuous improvement of the process. Their direct responsibilities include measuring of process performance and training of employees who perform the tasks. (Smart et al. 2009: 14; Hammer and Stanton 1999: 111-112.) The owner of the process, nevertheless, does not have the authoritative ability to determine the resources in the context of several units and therefore is forced to manage the process, closely collaborating with heads of these units and organization. In the case of the existence of several horizontal processes, the owner of the process usually interacts with other owners, forming steering or improving committee. (Hammer and Stanton 1999: 111-112.) Using these committees, it is possible to build mutual understanding and collaboration, for example, between several units of the company.

The existence of different types of groups, teams, and roles for the development, support, and performance of the process, in addition to their definition, requires clear rules for decision making. These rules are determined not only for the effectiveness of the units, but also for the overall environment. (Hammer and Stanton 1999: 111-112.) By establishing the rules, the development and support of the process take place in the most appropriate way, taking into account all stakeholders. There is a huge amount of matrix tools for visualizing roles and responsibilities. Most of them were created on the basis of RACI principle. The original tool represented as a matrix with roles or names in one plane and tasks in the other. The matrix cells fit the participation of various roles in the performance of tasks or results. There are four responsibilities in the main method, which are: *Responsible*, *Accountable*, *Consulted*, and *Informed*. (Kesler, 2016.) One of the most popular versions of this principle is RAPID (*Recommend, Agree, Perform, Input, Decide)*, developed by Bain & Company. The responsibilities of these methods described in the table below.

Table 11. RACI and RAPID method's responsibilities description (Adapted from Rogers and Blenko, 2006; Blomqvist, 2017).

| Method | Responsibility | Description |
|---|---|---|
| RACI | Responsible | Those who do the work to complete the task. |
| | Accountable | Ultimately answerable for the correct completion of the task. Delegates the work to Responsible |
| | Consulted | Individuals, to be consulted prior to a final decision or action |
| | Informed | Those who are kept up-to-date on progress, needs to be informed after a decision or action is taken. |
| RAPID | Recommend | Those who are responsible for making a proposal, gathering input, and providing the right data and analysis to make a sensible decision in a timely fashion. |
| | Agree | Those who have veto power over the recommendation. Exercising the veto triggers a debate between themselves and the recommenders, which should lead to a modified proposal. |

| | | |
|---|---|---|
| | Input | Those who are consulted on the decision. Because the people who provide input are typically involved in implementation, recommenders have a strong interest in taking their advice seriously. |
| | Decide | Those who are formal decision maker. Ultimately accountable for the decision, and has the authority to resolve any impasse in the decision making process and to commit the organization to action. |
| | Perform | Once a decision is made, a person or group of people will be responsible for executing it. In some instances, the people responsible for implementing a decision are the same people who recommended it. |

As seen from Table 11, both of these methods offer similar practices for defining responsibilities. The organization can use any variations of the tools that it considers appropriate for the processes. Nevertheless, these methods have some risks. Firstly, it is the risk of the emergence of several responsible persons and the uncertainty of who ultimately must make the final decision. Secondly, the excessive spread of the right of veto. Too many people with the right of veto can lead to a situation where proposal will never be brought to the stage of implementation. (Rogers and Blenko, 2006.) And finally, as Kesler (2016) noted, this is the excessive simplicity of these tools for complex decisions.

The RACI type tools can be convenient for the initial definition of roles and responsibilities. Nevertheless, as Kesler (2016) suggests, the final definition of responsibility in matrix organizations requires the use of practices for establishing a dialogue by defining a common direction, strategic goal, depending on the operational model of the processes. These prerequisites for the effective development of the process can be achieved through improvement of collaboration and communication skills of the company, which will be discussed next.

## 4.4 Improving Collaboration and Efficient Communication in Organizations

Effective implementation of the process and the work of the organization and management systems require consistent communication and collaboration (Martinsuo and Blomqvist 2010: 10). The creation of collaborative and communicating organizations for a long time worries many authors and the organizations themselves. Earlier, in the Subsection 4.2 was mentioned the interconnectedness of managerial processes. Returning to this topic, Bitici et al. (2011) based on the analysis of different companies identified five management processes, such as managing performance, decision making, communication, culture, and change. As further research showed, increased attention to communications and culture has a positive effect on other managerial processes, thereby increasing the efficiency and productivity of the company. (Bitici et al. 2011: 8-10.) This observation and the finding from the Sub-section 4.1, where the effectiveness of various development approaches in group culture was revealed, emphasize the improvement of communications as one of the fundamental prerequisites for organization’s efficient performance. The development of communication and teamwork is especially important in high-tech companies, such as engineering companies (Ullman and David 2009: 67). These companies conduct their work in close contact with many parties. Therefore, teamwork is the center of success in carrying out tasks.

As discussed in the previous sub-section, the definition of horizontal roles in the context of several vertical organizational units also allows improving the communication. In this case, the managers of both vertical and horizontal groups contribute to the development of communications facilitating internal information flow and external communication. External communication usually refers to the exchange of information with an external customer or a service provider. (Bitici et al. 2011: 7.)  In some cases, this type of communication includes benchmarking, which can also be conducted internally. In this case, good practices and ideas can be found, for example, among company’s other units, even if their processes radically differ from each other. (Klaus and Kumta 2014: 296-267.) Internal communication refers to the exchange and sharing of information between the personnel of the company, the group, the team etc. (Bitici et al. 2011: 7). So, for large organizations with high-tech products, the development of both external and internal communications is key in accumulating experience.

In companies where knowledge and experience play a significant role in the effectiveness of processes, it is especially important to develop both cross-functional and vertical communication by using common interest and teamwork principles. The principles state that collective creation and transfer of knowledge can be successful only in the case of established common interests, common data filling and organization practices, including formal and informal types of cooperation. Established common interests bring together people, different teams and groups, helping to exchange experience, and knowledge. (Klaus and Kumta 2014: 180, 237.) As noted by Ullman and David (2009), the paradox of engineering companies is in use of formal and informal forms of communication. Any communication begins with informal discussions or conversations. Therefore, there is a risk that the obtained information can be undocumented. This, in turn, can lead to loss of information or its inadequate processing in the form of missing documents, standards or instructions. (Ullman and David 2009: 137.) This in turn can complicate improving of the process and disrupt the morale of young employees. To eliminate this risk, it is important to have established practices for documenting and distributing information. (Staats and Upton 2011: 108-119.) Informal communication, supported by formal communication, creates strong alliances of workers, possessing considerable abilities to solve problems and complex tasks (Klaus and Kumta 2014: 99). These informal teams can strengthen the common eagerness to develop, reinforcing the internal interaction favorably affecting the quality of the performance of the processes.

All that flows between activities of processes, including the interaction between processes, is information (Bitici et al. 2011: 12). Information is formed by the connection of data with meaning (Klaus and Kumta 2014: 33). Thus, information can be correctly interpreted only with the adequate data and clear rules for its filling and processing methods. In modern organizations, the use of databases and software modules is an effective solution for rapid exchange and storage of data (Hammer and Stanton 1999: 111). This, in turn, improves the cooperation and collaboration of the various units of the company. Thus, the basic prerequisite for their development is correctly presented information, in the right place and at the right time. This allows companies to share accumulated best practice and knowledge with the further development of competence and competitiveness. (Klaus and Kumta 2014: 211, 296-297.) Nevertheless, companies may face the problem of finding information and its timeliness and reliability. To establish clear rules and control the flow of information, the company initially takes care of information management.

The importance of information management is underlined by Klaus and Kumta (2014) as the first stage on the way to the maturity of the knowledge organization. The introduction of information, communication technologies and the provision of specific access to databases and documents help to increase the transparency of the process. This leads to avoidance of double work and reduction of training time for new participants with a further improvement of the quality of products and services. (Klaus and Kumta 2014: 38.) Thus, by developing common databases, maintaining control over the creation and quality of data, the company can achieve desired cross-organizational communication level that will lead to active cooperation between different individuals, forming a formal and informal group of experts to maintain sustainable development and creation of innovative ideas.

The development of communication and collaboration in the organization also requires the establishment of a strategy and clear plan (Klaus and Kumta 2014: 151-152). First it is necessary to determine who will communicate. This can be done by establishing a link between the activities of different stakeholders and instruments to determine the roles and responsibilities described in the previous sub-section. Also, the frequency of communication plays a huge role in the work processes of personnel. A significant amount of information can disrupt the concentration on more timely problems. At the same time, staff awareness can help to fix possible problems at earlier stages. This is the responsibility of managers, to determine the balance between the necessary and the additional information, simultaneously developing a common understanding between the participants of the organization. (Staats and Upton 2011: 8.) Finally, after identifying key stakeholders and content, to maintain cross-organizational communication and the prerequisites for active collaboration, it is important to define the tools of communication. This may be mailing, cloud services, databases, and text messages. (Klaus and Kumta 2014: 237.) A clear definition of the methods gives a clear picture of the communication culture of the company, which plays a huge role in large organizations with a significant amount and frequency of information flow.

### 4.5 Conceptual Framework

The purpose of this sub-section is to summarize the review of the described best practice, provide a brief description of the overall picture, and point to the tools and concepts that can be utilized for the practical process improvement later in Section 5.

During the literature review, key ideas and concepts on *how* to develop the engineering process were identified. These findings were presented individually and further summed up, forming a conceptual framework. The framework provides a visual representation of the main aspects of the process development relevant in this thesis. The framework is shown in Figure 10 below.

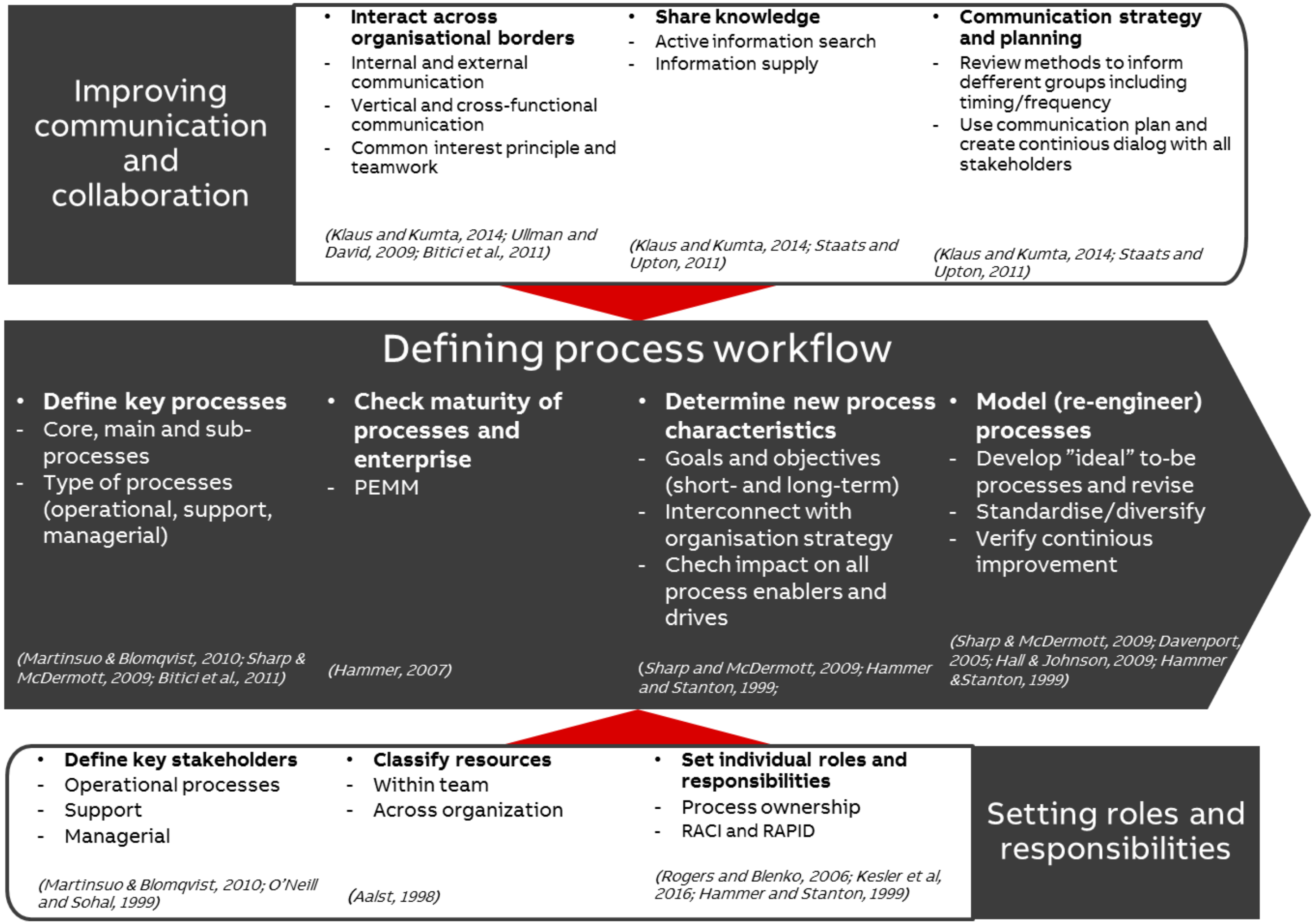



Figure 10. Conceptual framework for a process development in this study.

As seen from Figure 10, the conceptual framework includes three main elements of process development. The absolute core element of the framework relates to *defining the process workflow*, which is supported by two equally important elements, such as setting roles and responsibilities and improving communication and collaboration. These two supporting elements, in turn, interact with each other through the core element, forming an active system for developing the necessary process.

Defining of the process workflow, as seen from Figure 10, is formed by four sub-elements. The absolutely starting point of the core element is an identification of key processes with subsequent checking of their maturity and the capabilities of organization. This is necessary steps, which need to be done before further definition of characteristics of the process with an adequate set of objectives, in accordance with the company's strategy. At this stage, it is also necessary to describe the influence of process characteristics on various enabler for its effective operation. The final step in determining the workflow is to create a map of the ideal process, with subsequent corrections in accordance with the capabilities of the company and the defined characteristics. The end point of this element is verification of continuous improvement of the process, which can be done utilizing two remaining elements.

The next element of the framework relates to *setting the roles and responsibilities*. This element includes the definition of key stakeholders for various types of processes. Next, the resources for an effective operation, management and support of the process need to be determined using the classification of resources, followed by the definition of their individual roles and responsibilities. This section includes the use of popular tools for determining and grouping resources used in the development of business processes.

The last element of the conceptual framework relates to *improving the communication and collaboration.* The element consists of three sub-elements, including interaction across organizational borders, knowledge sharing and communication strategy and planning. This element includes the definition and clear presentation of techniques and rules of communication with the simultaneous installation of communication management in the organization. This is a necessary prerequisite for creating an enabling environment for collaborative work and supporting the company's processes in constant development.

To test the effectiveness of this model, it was applied to building the proposal for improving the 3D mechanical engineering process in the case company. The proposal was created utilizing this model and data obtained from the company's stakeholders during the next stage of the study and will be presented and discussed in the next Section 5.

# 5 Building Proposal for 3D Engineering Process for the Case Company

This section combines the results of the Current State Analysis (Data 1) and previously presented conceptual framework towards the building of the proposal using Data 2. First, this section overviews the proposal building stage to display the logic of its creation. Second, the section discusses findings from Data 2. Third, proposed improvements to the 3D Engineering Process are presented.

## 5.1 Overview of the Proposal Building Stage

During the CSA, several weakness and strength areas were identified regarding the current 3D engineering practices in the case company. After the detailed analysis, they were summarized into larger categories to point to the key findings from the CSA investigation. The main three issues, identified during this stage, were (a) the inefficient distribution of roles and responsibilities for process support and development, (b) the lack of defined workflow, and (c) the lack of communication and collaboration between three departments. At the same time, the analysis showed that the case company has strong environment, which cannot be utilized as a result of the abovementioned key weaknesses. Additionally, interesting findings from another company of the case organization were described.

The focus for the process development in the next proposal building stage is aimed at correcting the identified weaknesses. The weaknesses were clearly reflected in the conceptual framework represented by three closely interrelated elements, which are (a) defining the workflow, (b) setting the roles and responsibilities, and (c) improving communication and collaboration. The conceptual framework was created on the basis of a review of concepts, ideas, and theories of process development. With the help of most relevant elements to the topic, the conceptual framework guided developing the optimal structure for process in this specific case.

The initial proposal was built in several stages. First, Data 1 field notes were re-examined to find the initial suggestions from key stakeholders, mentioned during the interviews. At this stage, relevant practices from another company of the case organization were also considered. During Data 2 round, they were discussed together with the stakeholders to increase the reliability of the conducted study. Second, relevant practices and tools found from literature were presented to the Development group and other stakeholders with subsequent discussion and conducting the interviews. At this stage, the workflow design practices, Process and Enterprise Maturity Model, resource classification and RACI tools were utilized. Finally, the collected material, including the defined process characteristics, goals and objectives was used as fundamental guides during the creation of the new process map, with subsequent determination of roles and responsibilities with a focus on efficient communication and collaboration.

## 5.2 Findings of Data Collection 2

Findings from the second data collection round guided the proposal building stage. Data 2 consists from suggestions provided by key stakeholders during interviews, workshop and discussions. The suggestions deal with identified during the CSA weaknesses and relevant practices from literature. Since the conceptual framework addresses three key weaknesses of the current process, the suggestions were also divided into the same key areas. The main areas were defining process workflow, setting roles and responsibilities, and improving communication and collaboration. The results from Data collection 2 have led to the formulation of the initial proposal described below.

### 5.2.1 Defining the Process Workflow

Initially, before discussions with key stakeholders about possible suggestions, core and main processes related to the 3D engineering process were identified and illustrated as simple map, presented below.

Figure 11 below shows the process structure of the case company in the context of the 3D mechanical engineering process. The figure illustrates the interconnection of key horizontal and vertical business core processes and location of the main process in the entire system.

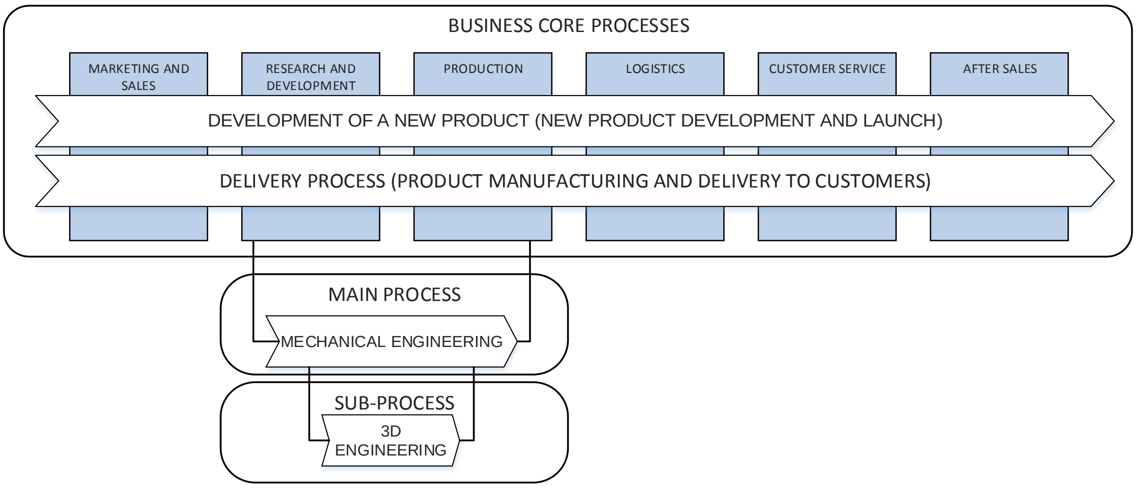



Figure 11. Business core and main processes related to the 3D mechanical engineering process in the case company.

As seen from Figure 11, there are two core processes related to 3D mechanical engineering. The core processes are *development of a new product* and *delivery process*. These two processes have a common main process, such as *mechanical engineering*. The 3D engineering process is presented as a sub-process of the mechanical engineering process. Since realistic goals and objectives of the process being developed can be determined only in case of awareness about environment capacity, the maturity of the main process and maturity of the case company were identified with the help of PEMM tool, filled by key stakeholders. The filled tables can be found from Appendices 6-8. The results showed that the main processes in the case company are stable, reliable and predictable. The case company in the same time have some experience with teamwork, but for further development it is necessary to invest in the competence of employees, the integration of electronic systems in the processes and practices of process development. These findings are also interconnected with the company's strategy, part of which are cooperation, leadership and excellence in operational processes. This information allowed the stakeholders to see the prerequisites for the development of the current 3D engineering process and to focus on the most relevant issues during discussions.

Table 12 below presents stakeholders’ suggestions and their brief description regarding process workflow key focus area from the CSA and the conceptual framework.

Table 12. Key stakeholder suggestions for proposal building (Data 2) related to process workflow key focus area from the CSA (Data 1) and CF.

| Key focus area from CS and CF | Suggestions from stakeholders | Description |
|---|---|---|
| Defining process workflow | a) Create a clear common process description/general guideline that everyone would use the software in the same way | The senior mechanical designer- and super-user, Local application owner and Head of Asynchronous machines department suggested to create a common process map describing each step of 3D mechanical engineering, which can be used by stakeholders, especially by inexperienced ones and new designers. |
| | b) Define practices for creation of component libraries to facilitate their use in assemblies and harmonization of data | Asynchronous machines designers proposed creation of component libraries, which include lists of created components for their fast finding. They can be integrated into the PDM system for use in assemblies. Additionally Global application manager suggested to pay attention on data harmonization practices. |
| | c) Establish the prerequisites for the development of process automation | The absolute majority of the respondents, including Head of Asynchronous machines, Global application owner, Super-user advised to consider the necessary steps for the development of parametric models and configurators and to include them in the development of the process. |

As seen from Table 12, the first key focus area arose three types of suggestions provided by the stakeholders. During all data collection rounds, the stakeholders repeatedly raised the need to create a clear common process map describing each step of 3D mechanical engineering, which can be also used by inexperienced and new designers. The process can be divided into stages as an instruction for completing mechanical engineering work in 3D. Indeed, as stated earlier in Section 4, lack of instructions affects the courage to act independently in young employees. As illustrated during the CSA, the current process map shows a strictly technical process, for the most part performed by one designer without a clear definition of the practices of storing and filling data as a result of their absence. The following suggestions refer specifically to this issue.

During the workshop conducted by Asynchronous machines mechanical engineering department, designers were divided into several groups for the brainstorming stage. Three of six groups suggested the ideas related to creation of reference libraries, naming instructions and standardizing of data storage locations. This topic, related to data harmonization, was also raised during the conversation with Global application manager (Data 1). The importance of data quality and methods of its distribution has also been repeatedly mentioned in Section 4 as one of main prerequisites for the effective development of communication and collaboration in organizations.

Next, one of the most relevant topics related to the workflow defining and continuous improvement of the process and touched by the stakeholders is the determination of the necessary steps for development of automation of the 3D mechanical engineering process in the case company. From the point of view of the majority of stakeholders, this is the future of the 3D engineering processes. Nevertheless, the fulfillment of this complex task requires instructions and training of the development team. Additionally, during Data collection 1, Global application manager mentioned the importance of collaboration with external experts, which is reflected in the literature review as one of the practices to improve the level of organizational knowledge.

### 5.2.2 Setting Roles and Responsibilities

The second area of stakeholders' suggestions relates to defining the roles and responsibilities for process support and development. Table 13 below presents the stakeholders' suggestions and their brief description regarding this key focus area, in relation to the CSA results and the conceptual framework.

Table 13. Key stakeholder suggestions for proposal building (Data 2) in relation to setting roles and responsibilities key focus area from the CSA (Data 1) and CF.

| Key focus area from CS and CF | Suggestions from stakeholders | Description |
|---|---|---|
| Efficient distribution of roles and responsibilities for process support and development | a) Determine the preliminary resources for creation of parametric models and configurators | Super-user, Global and Local application owners suggested to allocate roles for the creation of parametric models and configurators and describe their responsibilities in the case company. |
| | b) Define the roles and responsibilities to form a stable engineering workflow | Global application owner suggested to describe roles and responsibilities in terms of 3D engineering process and it's continuous improvement |
| | c) Distribute engineering work in accordance with the level of its complexity and experience of the employee | Head of R&D department (Another company of the case organization) suggested to distribute 3D engineering tasks according to complexity level and designer's experience for more efficient performance of engineering work |
| | d) Establish control over created data | Head of Asynchronous engineering department suggested to classify roles according to new process for data control and process support |

As seen from Table 13, this key focus area points to four types of suggestions provided by the stakeholders. First, the technical development of the process by automation in itself requires resources. Insufficient resources for performing such tasks were mentioned throughout the interviews. One of the first steps to efficiently allocate them and define a clear concept of necessary resources is, in the opinion of the stakeholders, the definition of their responsible areas, with subsequent distribution within the company. Noteworthy, the need to describe and define roles and responsibilities in the process was repeatedly mentioned during Data 1 and 2. As the current state analysis showed, the case company has clearly defined roles in Support organization, but the roles and responsibilities of the other process stakeholders are either absent or blurred and non-transparent for all parties. Global application owner suggested to determine who is responsible for decision making in various situations and who needs to be informed. Literature offers many tools for defining and describing roles and responsibilities. Some of them were used during the proposal building.

During the interview with the Head of R&D department in another company of the case organization (Data 1), it was mentioned that the initial distribution of engineering work in 3D is based on the complexity of objects being modeled, while continuously increasing the level of experience of the designer to perform more complex tasks. Here, the human factor also plays a role. As the interviewer mentioned:

> *You can distribute bulk stuff to certain people. I noticed that some designers made the bulk items in 2 minutes and others are thinking about the hour and they didn't get anything. (Head Manager R&D, Unit X)*

In this case, it is the work of the manager, take care of the correct distribution of tasks. Additionally, the idea of resource classification presented to the head of one of the departments was received with enthusiasm. According to the interviewer, this can help to allocate resources more adequately while improving skills and establishing control, especially in conditions of insufficient experience in 3D modeling. At the same time, the head of the department noticed that this idea was also discussed earlier:

> *For some time we are considering the possibility of defining individual roles to perform certain tasks. It makes sense. It is necessary to describe their areas of responsibility. (Head of department, Asynchronous machines)*

Thus, the need to describe roles and responsibilities regarding certain types of activities was raised again and was taken into account in building the initial proposal. In addition, the classification of resources was also mentioned in the context of improvement of communication and collaboration in the case company which will be discussed next.

### 5.2.3 Improving Collaboration and Communication

The last area of stakeholders' suggestions relates to improving collaboration and communication within three engineering departments. Table 14 below presents the stakeholders' suggestions and their brief description regarding this key focus area from the CSA and the CF.

Table 14. Key stakeholder suggestions for proposal building (Data 2) in relation to collaboration and communication key focus area from the CSA (Data 1) and CF.

| Key focus area from CS and CF | Suggestions from stakeholders | Description |
|---|---|---|
| Efficient collaboration and communication | a) Identify prerequisites for creating common instructions and 3D entities and distribution of information within stakeholders | Super-user suggested to describe practices for creation of instructions and models on the basis of initial approval by all involved parties.<br>Senior mechanical designer suggested to establish clear rules for information sharing based on common interest principle and teamwork |
| | b) Determine the necessary practices for communication and collaboration with R&D | Senior mechanical designer suggested creation of cross-functional group for establishment of a group's review on the upcoming new product lines and their updating. The rules of communication must be described. |

As seen from Table 14, according to the senior mechanical designer cross-functional teams, created on principle of common interest may break the barrier between mechanical engineering departments and R&D department. In this case classified resources may have direct contact with each other in formal and informal type of communication. The designer emphasized especially communication before, but also during and after new product line development or major updates of the existing products, which can significantly affect the mechanical engineering.

The need for awareness of all involved parties was also emphasized repeatedly during data collection rounds. All three departments operate in a common environment, where common databases and software are used. Therefore, any changes, updates and decisions in the opinion of the stakeholders should be approved by all interested parties. A good example here is the creation of instructions. According to many respondents, the company does not need to create detailed instructions for each type of the product. Vice versa, the company needs only general instructions that can be used by the majority of designers in different departments. Another company used this logic during creation of instructions. According to the stakeholders, the practice of creating instructions should include approval by all departments, which also includes distribution of information to all interested parties.

### 5.3 Proposal Draft

Before the initial proposal building, in addition to the findings described previously, the characteristics, goals, participants and tools of the new process were identified and filled into the table presented below. The table was filled during interviews and discussions with the stakeholders. The full list of proposed characteristics can be found from Appendix 9. Table 15 below presents sub-processes, identified weakness areas, short- and long-term goals, participants and tools.

Table 15. Main characteristics of the new 3D engineering process.

<table>
<tr><th colspan="7">3D Engineering Process</th></tr>
<tr><td>Event</td><td colspan="5">Sub-processes</td><td>Result</td></tr>
<tr><td>Designer needs 3D entity</td><td>Reference search</td><td>Instruction search</td><td>Modeling</td><td>Data filling</td><td>Checking & Approving</td><td>Designer use 3D entity</td></tr>
<tr><td colspan="4">Assessment</td><td colspan="3">Goals (Short-term) approx. 1y</td></tr>
<tr><td colspan="4" rowspan="3">- Our support chain is not transparent in whole organization<br>- There is a gap in communication between R&D and mechanical engineering departments<br>- Data is not harmonized<br>- There is identical data creation accidents<br>- There is a lack of instructions as a result of lacking resources for development<br>- There is no process description<br>- There is lack of common approach</td><td colspan="3">- The support chain is transparent for entire organization and support staff is available in each department<br>- The process described end-to-end<br>- The process description is easily available and user can name it<br>- The creation of identical data reduced<br>- Design approaches are checked</td></tr>
<tr><td colspan="3">Goals (long-term) approx. 3y</td></tr>
<tr><td colspan="3" rowspan="3">- More than 90% of needed instructions are available<br>- More than 90% of standard items available in 3D with standard ID and data is harmonized<br>- Reduced time of 3D engineering by utilizing of parametric models<br>- Performers are skilled in teamwork<br>- Each performer utilize common approach, which is clearly described and understood<br>- Performers are skilled, can name the process support staff and process<br>- Some configurators built in 3D</td></tr>
<tr><td colspan="2">Participants</td><td colspan="2">Tools</td></tr>
<tr><td colspan="2" rowspan="3">- Designers<br>- Key-users<br>- Super-users<br>- Application owners<br>- Controllers<br>- Developers</td><td colspan="2" rowspan="3">- 3D software<br>- TC<br>- Wiki</td></tr>
<tr><td colspan="3">Goals (long-term) approx. 5y</td></tr>
<tr><td colspan="3">- 3D technology supports engineering process's performance and management and allows analysis of environmental changes and process reconfigurations</td></tr>
</table>

As seen from Table 15, the established short-term goals mainly cover the workflow key focus area of the CSA and conceptual framework. At the same time they are quite clearly reflected in the suggestions proposed by the stakeholders. Thus they were taken as a basis for modeling the workflow.

Due to the large size of proposed process map, each step of the process is presented and discussed individually. Nevertheless, due to the fact that the proposed process includes also new participants, their roles and responsibilities are presented first. Utilizing suggestions provided by the stakeholders and idea of resource classification found from the literature, it was proposed to classify the departments' resources internally into three categories. These three categories presented in Figure 12 below.

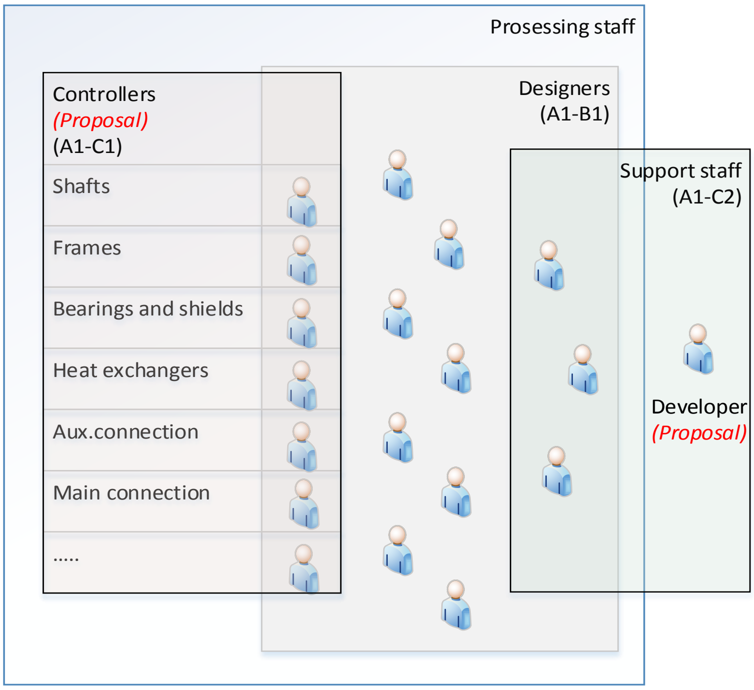



Figure 12. Department's internal resource classification.

As seen from Figure 12, internal classification includes two absolutely new roles, which are *controller* and *developer*. A detailed description of their responsibilities can be found in Appendix 11. The main distinctive feature of the developer role is the allocation outside the processing staff i.e. the developer does not directly participate in order engineering projects. Thus, 100% of his or her working time resourced for the development of 3D process automation and its support. The support staff in addition to the developer also includes the existing key- and super-user roles. Ideally, the super-user can become a developer, but their responsibilities and limited resourced time make this difficult to be concentrated, for example, on the creation of parametric models or configurators.

The most significant changes in the departments' internal structure may be observed with the appearance of controller role in the 3D mechanical engineering process. Initially, the controller is a designer who is a part of the processing staff. As a designer, controller's primary responsibility is mechanical engineering. As a controller, the additional responsibility of this category of staff is control over created data. The controller is responsible for created 3D data review, checking, listing and distribution. Different component areas, as seen from Table 12 distributed between different controllers and several categories can be delegated to one person depending on the case. The existence of this role in the process will help to establish control over the creation of data and minimize the risk of creating duplicate items while at the same time improving the quality of the design performed due to the constant checking of data by responsible persons. The participation of this role in the process is presented in details during the overview of the sub-processes.

As seen from Figure 12, the resource classification model also includes level of complexity of component design, which were presented earlier in Table 6. So for example designers have enough experience for correct modeling of A1-B1 entities, controllers until C1 complexity level, and the support staff full range of required 3D entities. Different resource classes have different modeling experiences so in terms of improving the level of design quality, it is very important to distribute the work in accordance with the level of experience. As the 3D engineering process will improve, experience and skills of all parties will also improve and this policy can be revised.

After the departments' internal resource classification, the process map describing the new 3D mechanical engineering process was created. The proposed process consists from five sub-processes, including the *reference search, instruction search, modeling, data filling,* and *checking and approving.* At the same time, a classic *modeling* sub-process has an alternative version which is *parametric modeling*. At the moment, the case company has a very small number of such models, but provided alternative sub-process map in good way illustrates difference of classical and parametric approach, emphasizing length of the process. Simplified entire process map presented in Figure 13 below.

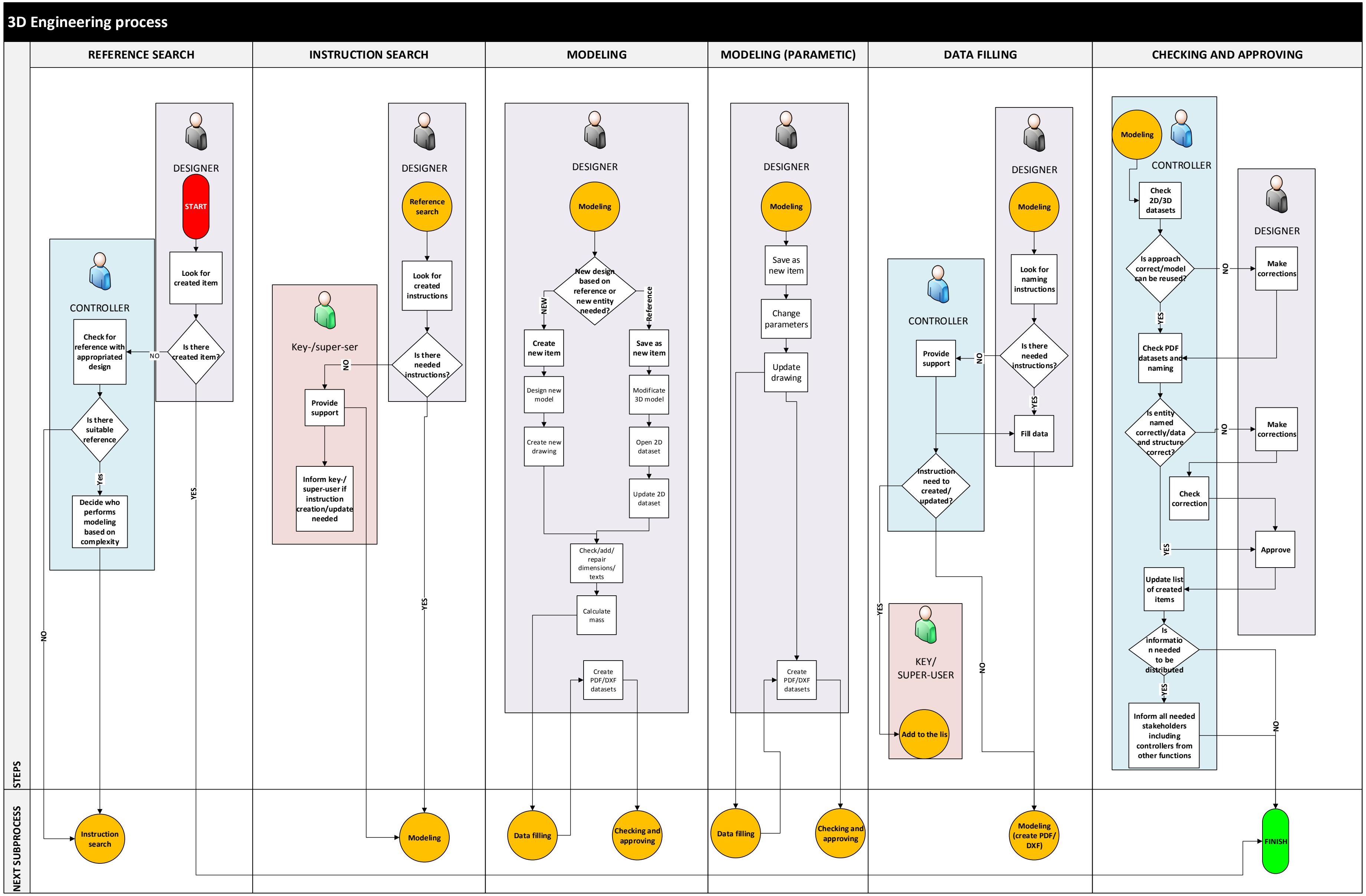



Figure 13. Proposed 3D engineering process.

As seen from Figure 13, in contrast to the existing process, the proposed process includes a more precise description of the workflow, emphasizing interactions between designer and controller roles. The proposed process map does not focus so much on the technical execution of 3D modeling, paying more attention to the logical chain of information generation and distribution of responsibilities. Each action has clearly defined responsible person. As controllers are also a part of processing staff and therefore designers, they can play the role of designers also. Nevertheless, it only partially changes the workflow, skipping some decision making activities. Next, each sub-process is presented individually. Figure 14 below illustrates the detailed *reference search* sub-process.

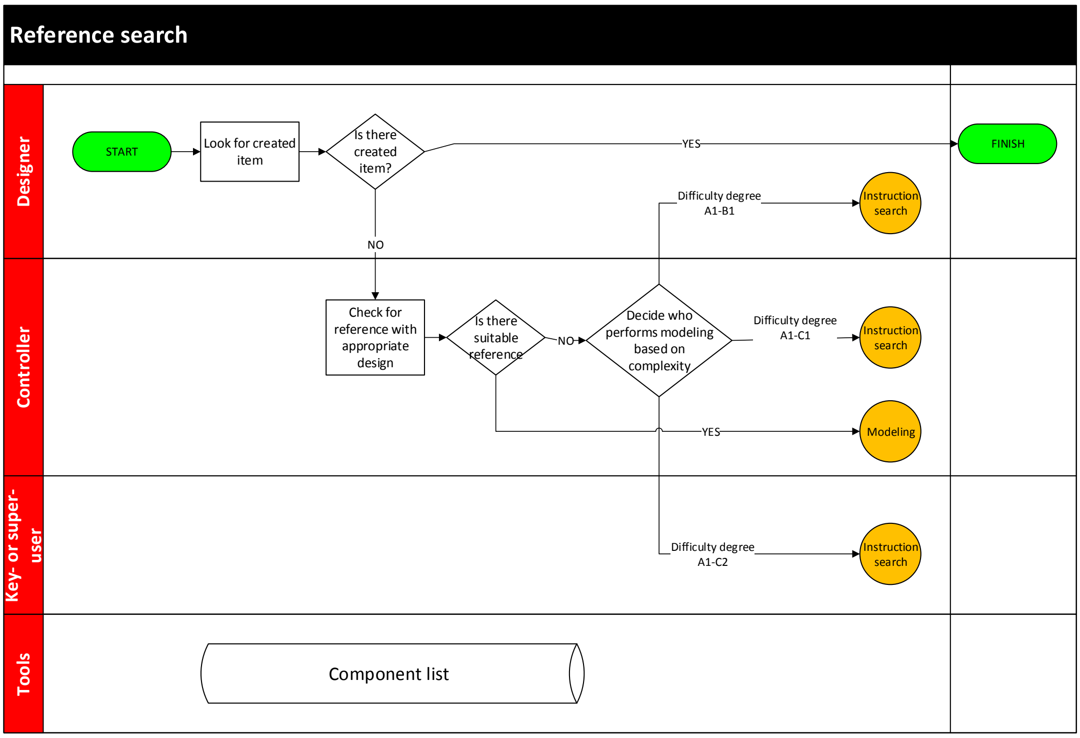



Figure 14. Reference search sub-process.

As seen from Figure 14, the 3D mechanical engineering process starts from the designer's need for some 3D entity. In the proposed process, before any start of new data creation, the search for already created data to be performed from being continuously updated by controllers or developers component lists. In the case of created entity's absence, the designer informs to responsible controller about the need for required component. The controller looks for a suitable reference from the component list and creates a new variation. If there is no suitable references for use, the controller decides based on the complexity level and competence of designer, who performs the modeling. The sub-process ends with the next sub-process, which is *instruction search*.

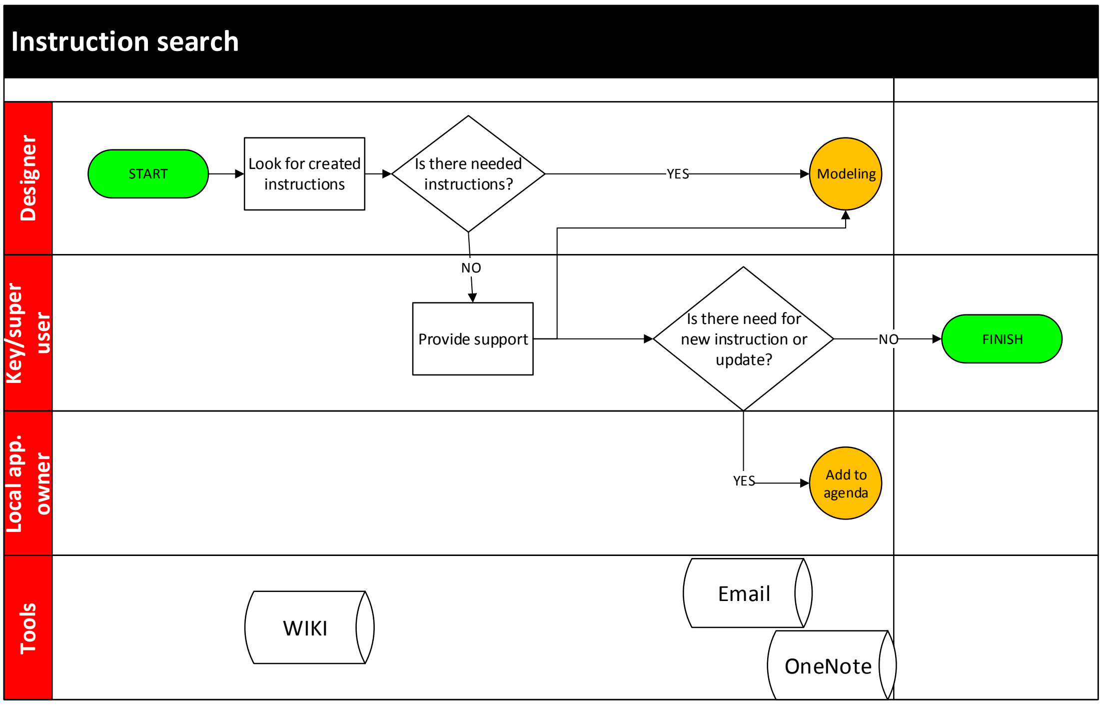



Figure 15. Instruction search sub-process.

Figure 15 shows that first activity of the *instruction search* sub-process is the search for already created instructions. The process continues normally and *modeling* sub-process can be started immediately if necessary instructions will be found. An important note here is that all instructions must be allocated to the same knowledge database. At the moment the company has practices of creating department specific instructions, which creates the risk of double work if similar instruction needed in another department. This topic is already presents in the agenda of Development group, where decisions are made to use and create only official cross-organizational instructions. In the case of an absence of needed instruction, key- or super-user provides support to the designer when simultaneously makes a decision on the need to create a new or update the existing instruction. If necessary, Local application owner will add the information about the need to Development group's agenda. The group will subsequently consider the proposal in the context of the three departments and will name the responsible person for its creation.

The process of modeling, as was mentioned previously, can be performed utilizing parametric model or classic creation or updating of 3D entity. Figure 16 below presents most commonly used option for creating a new entity.

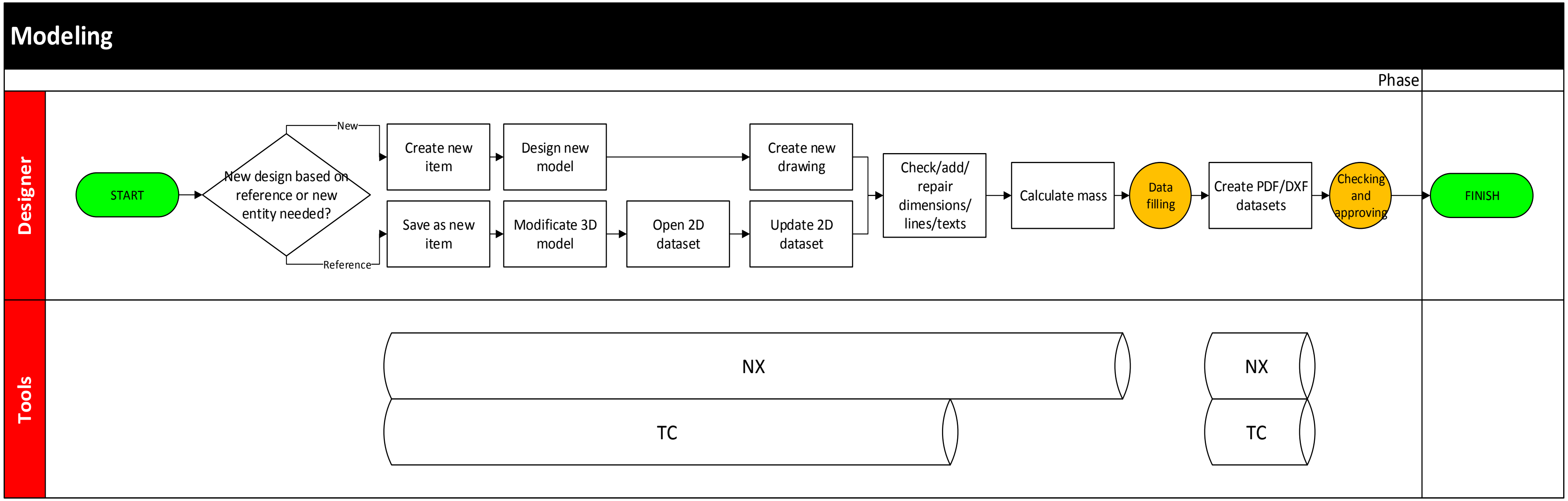



Figure 16. Standard modeling sub-process.

As seen from Figure 16, the sequence of activities described during the CSA does not differ from the one shown above. Due to the purely technical process, this part at the moment cannot be changed. Nevertheless, a certain part of this process can be automated in the case of using parametric models or configurators. The modeling process performed utilizing such models presented in Figure 17 below.

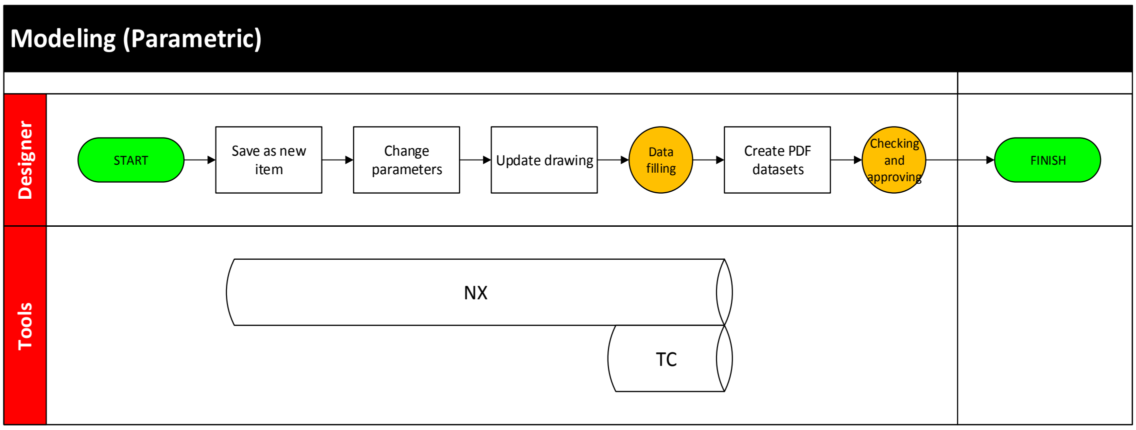



Figure 17. Modeling sub-process using parametric model.

As seen from Figure 17, the parametric process includes a smaller number of activities, and in itself is more efficient solution in the case of high component variability. The creation of parametric models is a laborious process, requiring extensive knowledge of the products and capabilities of the software. In the case of creating high-quality parametric models and configurators, the changing and updating of necessary components can be very effective, significantly reducing the design time. Thus, the use of these models is particularly favorable in Asynchronous machines engineering department due to the high variability of components' design and short delivery time. The benefits of usage of parametric models once again emphasize the need for the developer role in the case company. The development of process automation in turn allows to strengthen the tendencies of continuous improvement, which is also connected with the company's strategy.

*Data filling* sub-process was developed utilizing the recommendations of many designers and other stakeholders. The distinctive feature of this process is the availability of naming instructions for new data creation, including filling of entity's attributes in the system. The sub-process presented in Figure 18 below.

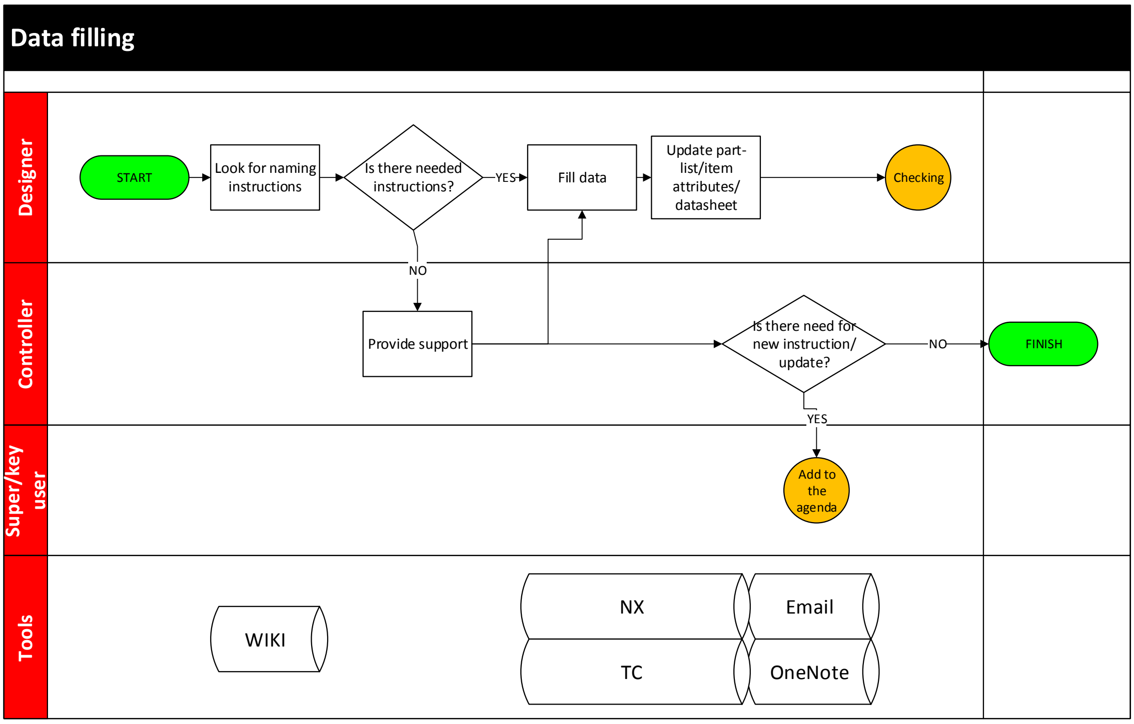



Figure 18. Data filling sub-process.

As seen from Figure 18, *data filling* practically repeats the sub-process of the instruction search, differing only in the *Fill Data* and *Update* activities. As in the case of instructions for design, naming instructions will be stored in common database, excluding the possibility of differences in naming of the similar components by different departments. In the case of an absence of needed instruction, the controller will ask key- or super-user to add the information about needed instruction to the Development group's agenda.

*Checking and approving* is the last step of the proposed 3D engineering process. Among the proposed activities of the sub-process can be underlined the changed order of checking, updating of component lists, and distribution of the information about them. The main difference between the proposed and existing checking practices is an alternate check of the design approach and structure in PDM system. The sequence of activities is shown in Figure 19 below.

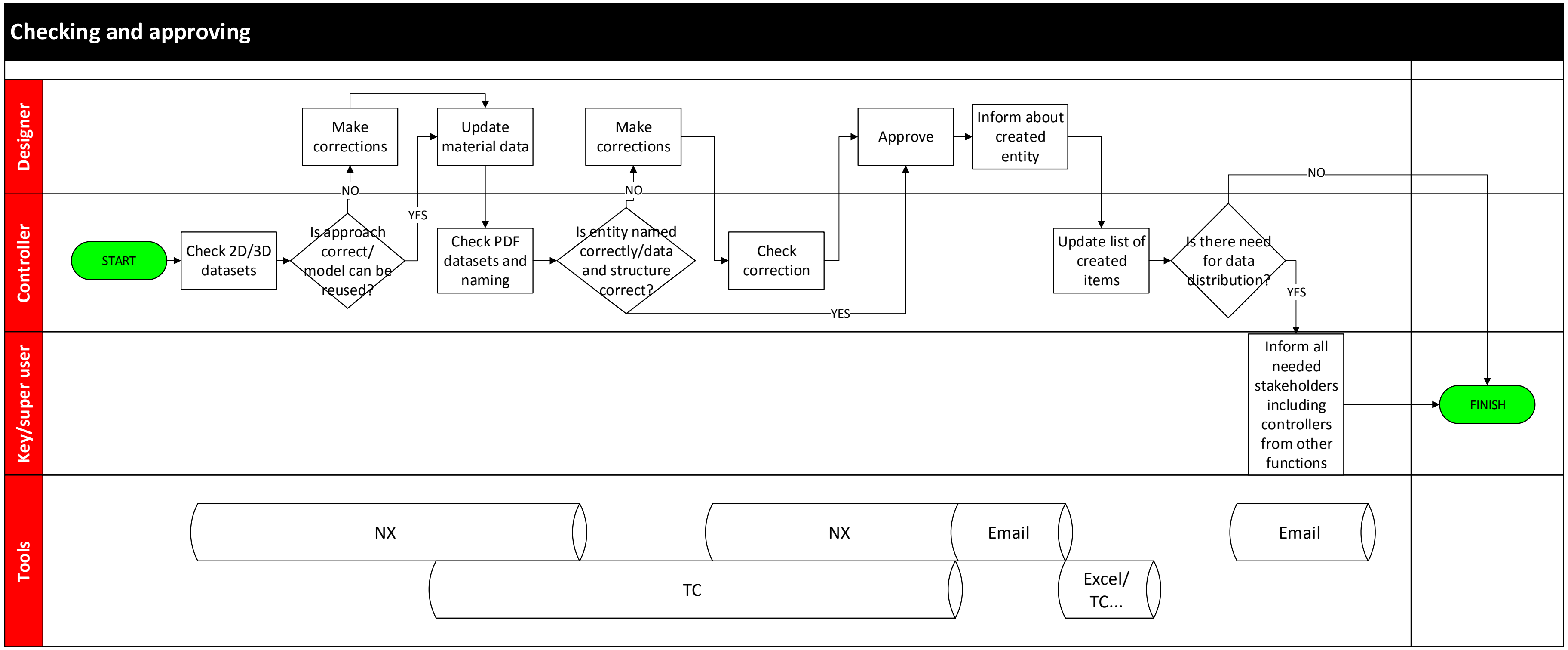



Figure 19. Checking and approving sub-process.

As seen from Figure 19, before any data or PDM structure checking, the utilized modeling approach and possible drawings need to be checked first. At the moment, due to the lack of connection between the material's attributes in the PDM system and the 3D model, filling of the material data before model's approving can take an extra step. If after the checking there will be need to update the model, the dimensions of the material or other material data needs to be changed in PDM also, which is a double work. After model's design, BOM and other datasets are checked, the new 3D entity can be approved in the system and used in structural design.

In contrast to the current process, the proposed process does not end at this stage. The controller, as the person responsible for monitoring of created data, will add the ID number of the created object into the component list. In case the created component can also be used by other departments, information about this will be distributed by key- and super-users among all involved stakeholders. Thus, the necessary information about already created components will help to avoid the creation of duplicates and structural design process can be performed more efficiently.

Frequency and volume of information distribution requires, as mentioned in Section 3 and Data 2, the establishment of clear rules for communication and collaboration. Utilizing resource classification practices used to determine department's internal resources, a cross-functional communication model was created and proposed for the case company. The resources were classified according to a similar principle in all departments and the structure of this model is shown in Figure 20 below.

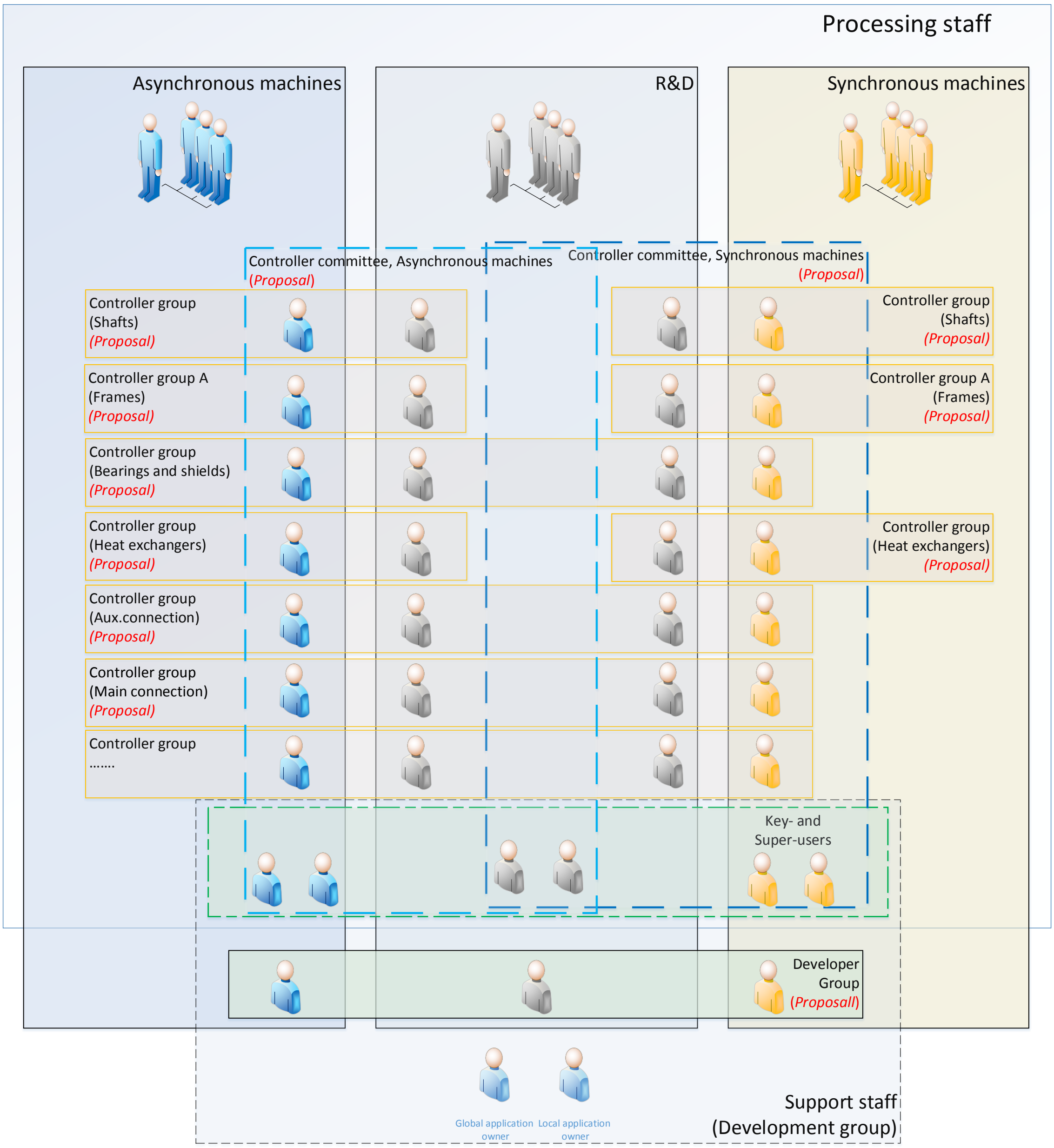



Figure 20. Cross-functional 3D engineering resource classification.

As seen from Figure 20, the proposed model includes in addition to already existing Processing and Support staff a number of several cross-functional groups, such as Developer group, Controller groups and Controller committees. A detailed description of these groups and committees, including methods and frequency of communication can be found in Appendix 11.

The main goal of proposed groups is to find common interest, create a stable dialogue between different stakeholders and more efficient use of resources. For example, the controller groups include controllers from different departments, thus increasing the level of awareness of designers about already designed components. Since the controllers are responsible for the overall monitoring of the generated data, common storage data systems and general design techniques can be used and maintained. These groups can consist of representatives of all departments in case the type of component is used in the design of both asynchronous and synchronous machines. If some components are used only in the design of one type of machines, the group includes representatives of one engineering department and R&D.

The controller committee in turn combines controllers of all component areas in the scale of certain type of machine. The main task of this committee is to improve collaboration of the mechanical engineering and R&D departments in the case of developing a new product line or improving the existing ones. This committee can help to discover common practices for creating 3D models, listen to design requirements from the point of view of different parties, and thus arrive at a common compromise. These committees are also supported by key- and super-users to provide technical support and required information on the capabilities of the systems.

The model includes some changes related to the support staff. The changes are the emergence of the developer role in the process and the provision of 3D support personnel in Asynchronous machines engineering department. The emergence of support staff in this department will help spread knowledge and information related to 3D engineering process equally to all users and provide a more transparent support chain for users. It is worth noting that the company does not have a separation of key- and super-users on the PDM and CAD system. Therefore, despite the official presence of support users in Asynchronous machines department, due to lack of 3D CAD experience they cannot efficiently provide support related to 3D engineering. As a solution to this issue, the company can provide additional training for these users or temporarily identify unofficial roles for 3D support.

Process developers are also included in the support staff, participating in the Development group’s meeting and being in close contact with other members of this group. At the same time, the developers forms Developer group. As in the case of other cross-functional groups, this group is created on the basis of common interests. This plays an important role in the development of parametric models and configurators, since the technique of their creation is for the most part the same for all departments. Thus, the development of process automation can take place on the same basis, strengthening the overall environment and mutual understanding between different departments.

In addition to the initial proposal, a table was created to describe specific practices of responsibility and awareness, describing the actions in relation to each type of resources. This table was created utilizing described in Section 4 RACI tool. It includes various situations, such as development of a new product, creation of instructions, standard item and parametric model, and data harmonization activities. The table gives a clear picture of who is responsible for carrying out a particular task, who needs to be informed and with whom to consult. A visual representation of the activities in different situations helps to establish control over communication and teamwork. The table can be found in Appendix 12.

In summary, the proposed elements of 3D engineering process development enable to undertake mechanical engineering in the coordinated way and provide prerequisites for its continuous improvement. The proposed workflow with new roles and description of their responsibilities with the focus on the cross-functional communication and collaboration can reinforce strong organizational environment and enable the possibility of creating common engineering platform.

Next, the Thesis proceeds to validating the initial proposal. The proposed elements were evaluated through key stakeholders.

# 6 Validation of the Proposal

This section reports on the results of feedback and validation of the initial proposal, presented in Section 5. First, this section overviews the validation stage to display the logic of its creation. Second, the section discusses findings from Data 3. Third, the section reports on the development to the initial proposal with subsequent presentation of the final proposal.

## 6.1 Overview of Validation Stage

The purpose of this stage was to evaluate the solutions proposed in Section 5 for eliminating the weaknesses identified from the current state analysis. The key weaknesses related to (a) the inefficient distribution of roles and responsibilities for process support and development, (b) lack of communication and collaboration between the departments, and (c) lack of the defined workflow. During the initial proposal building, the stakeholders' suggestions mentioned during the Data collection rounds 1 and 2, and the existing best practice found from literature were utilized with the focus on three key findings. The goal of this section was to build the final proposal for the effective performance of engineering work in 3D in the case company, utilizing the feedback collected during Data 3.

The validation of the proposal was done in two steps. First, the initial proposal was presented individually to the stakeholders including Global and Local application owners and new participants of this study. The new participants were actual performers of engineering work, which do not have sufficient experience with the used by the company 3D software. Both designers perform work for Asynchronous machines department. The choice was made on the basis of the critical need for using of 3D technology in this department and therefore the transparency and intelligibility of the proposed process can be clearly assessed by these actual users with minimal bias. The discussions with Global and Local application owners were focused on evaluating the initial proposal and further steps.

Second, based on the comments and recommendations, the final proposal was created and presented to the heads of the mechanical engineering departments to validate the proposal and assess the possibility of its implementation.

## 6.2 Findings of Data Collection 3

Findings from the third data collection round guided building the final proposal. Data 3 consists of the stakeholders' feedback to the initial proposal, and suggestions for further action collected during the validation round. Since the conceptual framework, the CSA key weaknesses, and the initial proposal focused on the same three key areas, the findings of Data 3 also utilized the same logic. The findings from validation and further development needs are discussed below.

### 6.2.1 Defining the Process Workflow

The first key focus area is *process workflow*. The proposed process map was presented to key stakeholders during interviews with consequent discussion. Collected comments were summarized into two categories and listed in the table below.

Table 16. Key stakeholder feedback to the initial proposal (Data 3) in relation to defining the process workflow.

| Key proposal area | Feedback | Description |
|---|---|---|
| Process workflow | a) Sufficiently detailed description of the process with clearly defined steps for the completion of the task | According to senior mechanical designers, Local application owner and Head of Asynchronous machines engineering department the proposed process description is reliable and can be used.<br>According to Global application owner the description may serve quite well new designers and less experienced designers. |
| | b) Control over data creation is described and the practice is adequate and reliable | According to senior mechanical designers the proposed controller role and, component lists offer a pretty good chance to take the data under control. Nevertheless precise guidelines referring to different activities such as updating, marking as obsolete and removing objects from list need to be established. |
| | c) Search for reference can be revised | According to one of senior mechanical engineers and Head of Synchronous machines department, “Is there suitable reference” activity and complexity levels can be removed from reference search step. It is too difficult and uncertain to define who have what level of experience. |
| | **Recommendations for future development** | |
| | a) Continues development and support of the process requires an action plan | According to Global application owner action plan's steps should provide a clear sequence of necessary actions and answer to question What, Who and When. Additionally Global application owner and Head of Synchronous machines engineering department have a strong opinion |

| | | |
|---|---|---|
| | | on the greater need for automation in Asynchronous machines than in Synchronous machines. |
| | b) Prioritization of development tasks | According to Senior mechanical engineer and Head of Synchronous machines in the case of urgent orders it is difficult to keep focus on the development. At the moment, there is no clear prioritization of tasks and daily priority overrules process development. There is a need to find right way to prioritize the tasks. |

As seen from Table 16, the two categories are feedback and recommendations for further steps. For the most part, the proposed improvements were welcomed positively with some requirements for adjusting the process. Most of the comments was directed to the following steps and possible obstacles that may occur during employing the proposed improvements. Collected feedback was utilized during the final proposal building and recommendations in the action plan. Each element will be discussed next.

The proposed process map, including the data control practices, was perceived as a reliable description of the developed process in accordance with the real situation. The map seemed understandable to the heads of engineering departments and directly to designers. The proposed improvements regarding the *reference search* were also discussed. One activity and complexity levels needed to be removed from the process map. Especially representatives of Asynchronous machines engineering department, due to the initial predisposition to the role of the controller and component libraries, took the idea positively but with comments on the need to manage already created and obsolete data.

According to Global application owner, the proposed map solves only one-time, urgent tasks. It can be used by the engineering departments, but an action plan is needed for further development of the process, that is, process's automation. In the case of the developed automation, in the long term such sub-processes as *reference search* or basic *modeling*, including drawing creation will become unnecessary. Asynchronous machines department was emphasized by many interviewers as the most favorable environment for the development of automation in connection with short delivery time and high level of component variability.

One of the most significant and topical recommendations is the prioritization of development tasks over daily activities. As mentioned in Data collection 2, at the moment, the time for performing these tasks is not resourced. The solution to this problem was suggested by introducing a developer role during the building of the initial proposal. Comments on this proposal are discussed next.

### 6.2.2 Setting Roles and Responsibilities

The second area of stakeholders' feedback and recommendations relates to *defining of roles and responsibilities* for process support and development. Table 17 below presents stakeholders' comments and their brief description regarding this proposal area.

Table 17. Key stakeholder feedback to the initial proposal (Data 3) in relation to the proposed roles and responsibilities.

| Proposal area | Feedback | Description |
|---|---|---|
| Roles and responsibilities for process support and development | a) The role of the controller in the process is very useful | According to the comments of representatives of Asynchronous department, the role of the controller is very useful and can facilitate the engineering process. Additionally, according to senior mechanical designers in this department a similar solution can be extended to the 2D design. |
| | b) We are ready to invest and allocate additional resources for the development of engineering automation | Head of Asynchronous machines and Global application owner have the ability to influence the allocation of resources in the case of detailed description of tasks and objectives |
| | c) The release of necessary resources for the development of automation can be difficult | According to Head of Synchronous department, there can be difficulties with the release of resources for process development at the moment due to high pressure and large volume of orders. Also R&D staff is focused on urgent projects. |
| | d) Insufficient motivation can become an obstacle in using the controller role | According to Head of Synchronous department, low motivation and user resistance can be obstacles on the way to data control with the new controller role. Additionally, according to Global application owner the controller role in R&D is difficult to determine in connection with the global function of the department and the large number of different product lines. But controller committee is useful and can be utilized. |
| | e) The execution of engineering work in accordance with the complexity can be reviewed in different departments | According to Head of Synchronous department and senior mechanical engineer, 3D engineering experience is on different levels in different departments, thus the distribution of engineering work cannot be equal everywhere. |
| | Recommendations for future development | |
| | a) Before allocation of resources it is necessary to define the necessary para- | According to Global application owner, there is need to define what parametric and configuration models departments need. Only after clear definition there is possibility correctly allocate resources. |

| | | |
|---|---|---|
| | metric models and configurators and train the personnel | |

As seen from Table 17, the feedback to data control varied by different stakeholders. Asynchronous machines department took the idea positively and, moreover, according to the senior mechanical designers, this practice can be extended to 2D design in this department, taking under control all types of created data. At the same time, Head of Synchronous machines engineering department mentioned that such an idea is convenient but can be met by user resistance because of lack of motivation. Nevertheless, as discussed in Section 4, the concern for employees' motivation is the responsibility of the department heads and is beyond the scope of the topic considered in this study. Global application owner who was also a representative of R&D department at the beginning of the research mentioned that using controller roles in the R&D department can be extremely difficult due to its global function and the large number of different types of designed products. Nevertheless, according to Global application owner, the proposed cross-functional committees can lead to positive results and should be tested first by one department.

The need to allocate additional resources was also perceived ambiguously by different respondents. Asynchronous machines department and Global application owner are ready to allocate the resources for effective development of the process and to influence this decision on executive level. Nevertheless, in their opinion, it is necessary to compile a complete list of the tasks to be done, determine the methods of development and the required training. This is also reflected in the recommendations for further actions.

At the same time, Head of Synchronous machines engineering department relies on the employment of staff due to the large number of orders and for this reason the allocation of individual resources is currently impossible in this department. Nevertheless, in the long-term perspective, there is possibility to allocate more time for process support and development for the department's super-user.

The proposed distribution of engineering work in accordance with the level of complexity and skills of the designer was questioned by one of the senior mechanical designer, Global application owner and Head of Synchronous machines engineering department. In connection with the different level of 3D usage and experience of the departments, the distribution of work on this basis may look ineffective. As was mentioned during interviews, with control and clear instructions, any designer will be able to perform various tasks while improving his experience level.

### 6.2.3 Improving Collaboration and Communication

The last area of stakeholders' feedback and recommendations relates to proposed improvements regarding *collaboration and communication between the three departments*. Table 18 below presents stakeholders' comments and their brief description regarding this proposal area.

Table 18. Key stakeholder feedback to the initial proposal (Data 3) in relation to the proposed communication and collaboration practices.

| Proposal area | Feedback | Description |
|---|---|---|
| Efficient collaboration and communication | a) There is a possibility to achieve a permanent dialogue, but it takes time. | According to Head of Asynchronous machines, Global and local application owners the creation of cross-functional groups will help to improve communication and collaboration in the case company but it requires big efforts by all parties and time. |
| | Recommendations for future development | |
| | a) Practices for creating common instructions and distribution of information to all stakeholders need to be described in detail | According to respondents it is necessary to utilize a clear platform for the distribution of information. Globally, the entire organization is working on this, it is necessary to monitor the development of communication and collaboration tools. |

As seen from Table 18, quite a few comments on this topic were made. The concept of the proposed cross-functional groups was perceived positively. Nevertheless, the need for the participation of all parties in the attempt to establish communication is called as the most important prerequisite for a stable dialogue. As one of the auxiliary tools for starting the construction of communication, the global environment was mentioned. In connection with the growing globalization, the company begins to eliminate local storage systems transferring them to a cross-organizational basis. The need to monitor changes and use joint tools is seen as an effective way for information sharing and collaboration improving and was reflected later in the action plan.

### 6.3 Developments to the Proposal Based on Findings of Data Collection 3

After the feedback to the initial proposal was collected and discussed to the proposal areas, the necessary immediate developments were identified, as presented in Table 19 below.

Table 19. Immediate developments to the proposal.

| Proposal area | Development |
|---|---|
| 1. Process workflow | a) Remove “Is there suitable reference” activity<br>b) Remove complexity levels from Reference search sub-process |
| 2. Roles and responsibilities for process support and development | a) Remove controller roles from R&D.<br>b) Define precise controller roles in Asynchronous Machines.<br>c) Leave provision for controller roles in Synchronous machines.<br>d) Remove separate developer role from R&D and Synchronous Machines.<br>e) Remove distribution of engineering work according complexity level |
| 3. Communication and collaboration | a) Describe tools and frequency for group’s communication<br>b) Remove cross-functional controller groups |

Table 19 shows the changes to the initial proposal based on the feeedback during the Data collection round 3. All these changes were made immediately, which was reflected on the process map, resource classification models, roles and responsibilities. So for example reference search sub-process was updated with the removal of one of the decision making activities and complexity levels. This is the only change related to the process map.

As seen from Table 19, the internal and cross-functional classification of resources has undergone the greatest changes. For example, the proposed roles of controllers in R&D department were removed. At the same time, in Synchronous machines engineering department a provision for controller roles left. These roles can be taken into use in case of successful testing of this concept in Asynchronous department. As a result of the liquidation of these roles, the cross-functional groups of controllers were eliminated. Nevertheless, they can be restored in case of successful testing of controller roles by Asynchronous machines engineering department.

The next change related to the proposed Developer group. The existing cross-functional Support staff was expanded but the role of the developer in Synchronous machines and R&D departments was temporarily removed. In the future, the active role of the developer can be also provided to the super-users of these departments. In any case, the role of the developer in Asynchronous machines department has remained, which can favorably affect not only the development of process automation but also the user support. In addition to these changes, descriptions of groups and committees including communication tools and frequency of interaction were updated. Next, the Final Proposal is summarized and discussed with sebsequent presentation of the action plan.

## 6.4 Final Proposal

Based on the findings from the CSA and utilizing the conceptual framework, stakeholders' suggestions and feedback to the initial proposal, the final proposal for 3D mechanical engineering process was built.

The summary of the final proposal devided into three parts according identified during the CSA key weaknesses and presented in Figure 21, 22 and 23.


Figure 21. Summary of the Final Proposal regarding the process workflow.

As seen from Figure 21, the first part of the final proposal's summary includes the main aspects of the workflow. The building of the final proposal was focused on the weaknesses associated with the lack of developed workflow as such. With the help of techniques for identifying key processes with further checking of the processes' and organizational maturity, the short- and long-term goals and characteristics of the new process were identified. The objectives and characteristics were determined jointly with the stakeholders in accordance with the organizational strategy of the company. This helped to see the full picture of the new process before its detailed description, making the mapping process more efficient. The final proposal for the process's workflow looks like a process map with a clear sequence of activities and defined responsible persons for each activity. The new process includes practices of control over the creation of data and user support. The idea of a new controller role and the use of component libraries was borrowed from another company of the case organization where the effectiveness of this method was proven in use. The user support in the new process based on the existing available local support and the role of the controller. The support is distributed in such a way as to minimize the use of incorrect modeling approaches and creating of identical data. The final process map can be found from Appendix 10.

The next part of the summary relates to the roles and responsibilities for process support and development. Figure 22 below illustrates key topics from different parts of the study used in the building of the final proposal.

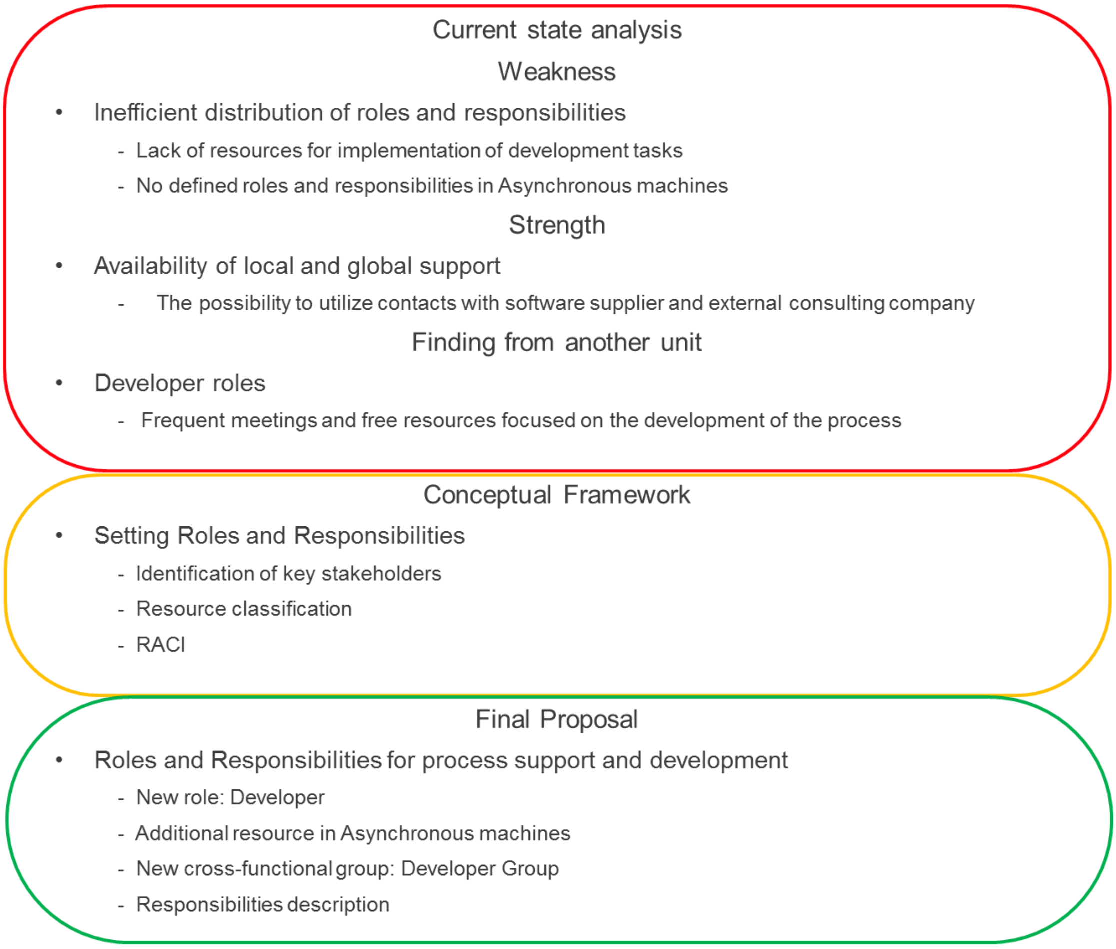



Figure 22. Summary of the Final Proposal regarding the roles and responsibilities.

After identifying the key stakeholders and their classification, the developer role was proposed on the example of another company of the case organization. Using the contact with the consulting company, the developer may be an external expert. Nevertheless, in view of the importance of the development of organizational knowledge, the proposed role is internal. Due to the high level of staff employment in other projects, the ability to determine additional resources is possible only in Asynchronous machines engineering department. At the same time, this department suffers from a lack of resources to support the process, so the allocation of an additional resources solves several problems at once. The final proposal looks like the introduction of the developer role in Asynchronous machines with, based on the result of testing, subsequent definition of this role in other departments and creation of cross-functional Developer group. The description of roles and their responsibilities can be found from Appendix 11.

The last part of the summary relates to communication and collaboration within the thee departments. Figure 23 below illustrates key topics from different parts of the study used in the construction of the final proposal.

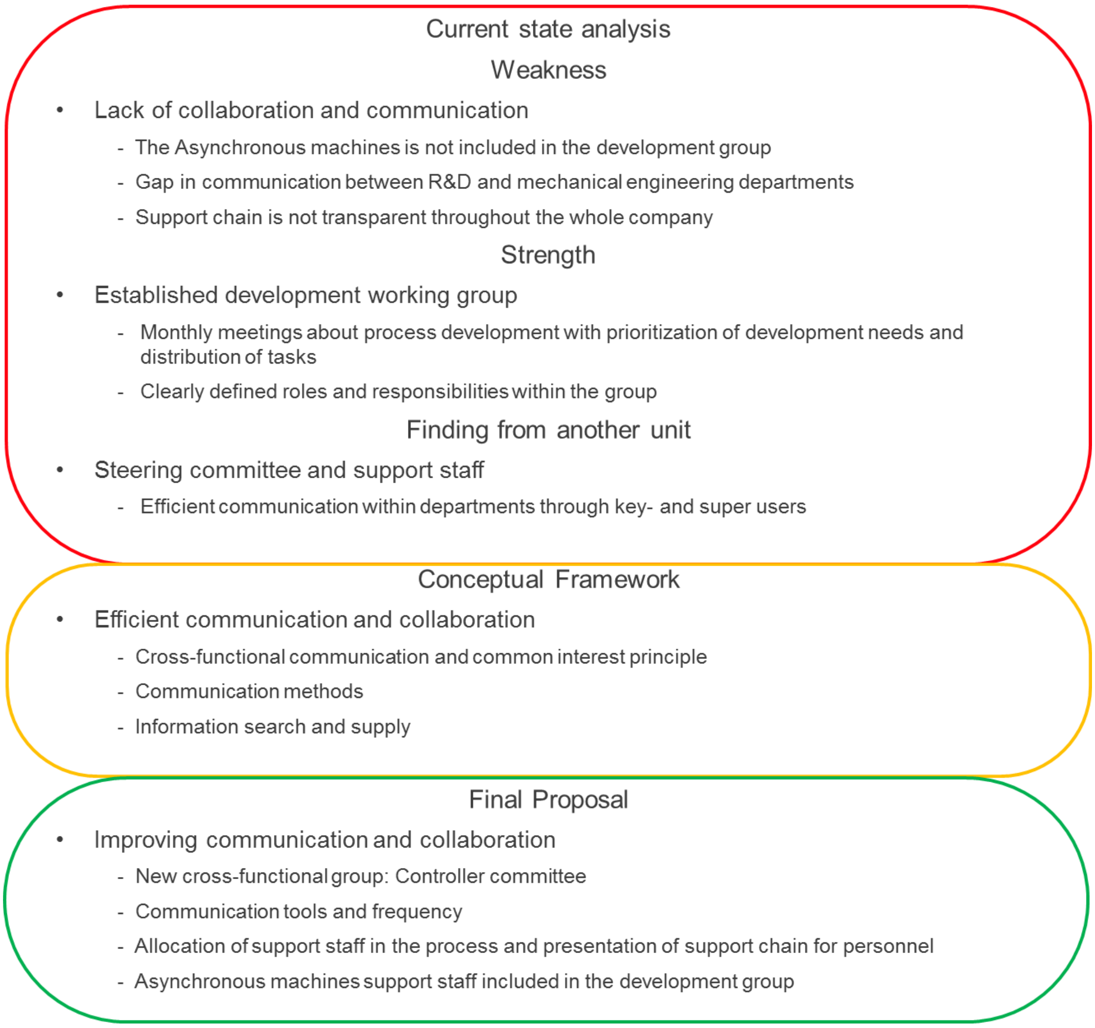



Figure 23. Summary of the Final Proposal regarding communication and collaboration.

Using methods of resource classification and the existing Development group, with an example of its use in another company of the case organization, it was suggested to include representatives of Asynchronous machines engineering department in the group. The presence of the new support roles in Asynchronous machines mechanical engineering department requires the presentation of the entire support chain for the staff to be aware of it. Using the cross-functional method of resource classification and principles of mutual interests described in Section 4, to achieve a stable dialogue between the departments it was proposed to establish a controller committee. This committee can help to create a constructive, continuous dialogue between R&D and mechanical engineering departments before, during and after the development of a new product or in case of major updates. Detailed description, including communication methods and frequency of the committee such as the other groups can be found from Appendix 11. Final cross-functional resource classification model presented in Appendix 13.

## 6.5 Action Plan

This study combines practices of process re-engineering and continuous improvement. Utilizing the re-engineering practice, the new process map was created, new roles and responsibilities, their methods of communication, etc. were identified. From the point of view of the continuous improvement, the process automation, the strengths of which have been mentioned repeatedly during the interviews, seems to be the most urgent goal for aspiration. The automation of the 3D engineering process was also mentioned as a part of 3- and 5-years goals. Using the recommendations described in Sub-section 6.2 and the current situation in the company, an action plan was created to develop automation of the engineering process using the proposed improvements.

The action plan presented in Figure 24 below.

| Phase | 1) Identify needed parametric models | 2)Achieve an equal level of experience | 3)Identify harmonization approaches | 4)Identify needed instructions | 5)Establish control over data | 6)Free resources | 7)Perform tasks | 8)Release | 9)Monitor and evaluate |
|---|---|---|---|---|---|---|---|---|---|
| What | • Identify needed parametric models by the joint efforts of all departments | • Increase use of 3D technology in Asynchronous machines department | • Identify approaches to data harmonization | • Identify Needed instructions by the joint efforts of all departments | • Establish control over created data | • Allocate resources for creating parametric models and configurators | • Perform the necessary tasks using dedicated resources | • Release created automation | • Monitor and evaluate process continuously |
| Why | • Joint definition reduces the risk of double work and establishes a dialogue between different stakeholders<br>• The definition is necessary for the further allocation of resources | • An equal level of experience should be achieved in all departments to efficiently improve the process and establish a constructive dialogue between all stakeholders | • Harmonization of data avoids double work. High-quality data allows its efficient processing and the ability to transfer from one system to another. | • Joint definition reduces the risk of double work and establishes a dialogue between different stakeholders | • Control over data allows to improve the quality of the output and avoid possible incidents of its incorrect use. Using high quality data may improve the quality and shorten the time of engineering work | • The creation of models and configurators, requires skills and focus on the process. The effective and reliable development of automation is impossible in the case of its long development. The environment can change faster than automation is developed. | • All the necessary conditions and a foundation for active development of automation implemented | • To effectively perform engineering work | • For the prevention of errors and the continuous development of the process in accordance with the changing environment |
| How | • Conduct a workshop with representatives of all departments and identify points of common interest | • Utilize process descriprions<br>• Provide a clear presentation of the support chain for designers<br>• Define support users in Asynchronous machines engineering department | • Identify the types of data that can be classified<br>• Identify the types of data that can be outsourced<br>• For other types of data, determine storage location and statistics | • Conduct a workshop with representatives of all departments and identify points of common interest | • Define the roles for data control<br>• Utilize the approaches defined in the previous steps | • Allocate at least one person/department for full time development<br>• Provide training for dedicated staff<br>• Check possibility of external support for benchmarking and external knowledge utilization | • Together with designers and according to condition of the global development of the process, prepare the necessary models and configurators.<br>• Test the automation on the example of one product line for each department<br>• Gather feedback | • Make necessary changes based on the feedback from internal customers<br>• Conduct a presentation of a new process for all stakeholders<br>• Train on using new techniques and collect feedback | • Establish practices for feedback gathering<br>• Install a stable platform to support the process<br>• Provide resources for support<br>• Monitor the global and local environment<br>• Interconnect process with company's strategy |
| When | • 24.4.2018 | • May 2018- | • May-June 2018 | • May-June 2018 | • July-August 2018 | • September 2018 | • October 2018-September 2019 | • September 2019-November 2019 | |
| Who | • Local application owner<br>• Asynchronous machines<br>• Synchronous machines<br>• R&D | • Head of Asynchronous machines engineering department<br>• Designers | • Global application owner<br>• Local application owner<br>• Super-users | • Local application owner<br>• Asynchronous machines<br>• Synchronous machines<br>• R&D | • Asynchronous machines engineering department (testing)<br>• Depending on the result, other departments later | • Asynchronous machines engineering department<br>• Synchronous machines engineering department<br>• R&D | • Global app. owner<br>• Local support staff<br>• Asynchronous machines<br>• Synchronous machines<br>• R&D | • Global App. owner<br>• Local support staff<br>• Asynchronous machines<br>• Synchronous machines<br>• R&D | • Global App. owner<br>• Local support staff<br>• Asynchronous machines<br>• Synchronous machines<br>• R&D |

Figure 24. Action plan.

The proposed Action plan shown in Figure 24 consists of nine steps with the explanation of the purpose, methods, participants and approximate time of execution. The first step of the action plan is to identify the necessary parametric and configuration models with the participation of 3D experts from all engineering departments to find the necessary points of mutual interest during their creation. The exact date for the workshop was indicated and sufficient time is reserved for the discussion.

At the same time, using the proposed process descriptions, and internal classification of resources, the use of the 3D software will be increased in Asynchronous machines engineering department. The rare use of 3D technology is one of the main obstacles to the joint development of the process. To establish a stable dialogue between three departments, it is necessary to achieve an equal level of experience in 3D design, which can be achieved only in conditions of increasing its use. At the same time testing of the principle of resource classification can be carried out by Asynchronous machines department. In case of obtaining positive results, it can be taken into use by Synchronous department at the fifth stage of the action plan.

The third and fourth stages include the definition of data harmonization methods and necessary instructions, including component’s naming instructions. As in the case of any other decision, the decisions relating to the creation of instructions and data harmonization practices will be carried out in a joint approval process by all involved departments.

Utilizing the approaches, tools and instructions defined in the previous stages, in the fifth stage, data control will be established. At this stage, depending on the results of testing the controller's role and accepted data classification methods, the model can be adopted by other departments with the subsequent creation of cross-functional groups.

Since all the prerequisites for the creation of parametric models and configurators have been met, the next step is to provide resources for performing the necessary tasks. Depending on the level of experience of selected developers, they can be provided with additional training by a consulting company. If necessary, the assistance of a third-party expert can be provided.

The following steps are a straightforward process of automation creation. The creation need to be done in close cooperation with local designers and by utilizing Global application owner’s contacts. Engineering process automation is a priority for many companies in the Production Group and by utilizing cross-organizational contacts, its implementation can be more effective.

The final release of parametric and configuration models requires careful testing and collection of feedback from designers before the official use of the developed automation. Only after performing the necessary improvements and making sure of the system's serviceability and the satisfaction of the designers as an internal customers, the system can be effectively launched and used. Additionally, the actual performers of the engineering work should be provided with the necessary training and support. These tasks can be performed by the developers involved in the development process, due to their “champions of the process” imago.

Like any process developed with the focus on continuous improvement, it does not end but continues to be improved through monitoring and evaluation of the output quality. Since the automation in the long term is able to reduce a number of resources executing directly technical tasks of the engineering process, these resources can be focused on the process support and improvements. Using the principle of freeing resources for the further development of the process, the optimal 3D mechanical engineering platform can be achieved by the case company.

The final proposal and the action plan were presented to the heads of mechanical engineering departments for review and assessment of reliability. According to the respondents, the final proposal and the action plan are reasonable and proposed schedule is realistic. The action plan will be updated as the required tasks are completed, but according to one of the departments’ heads, the identified steps need to be performed at an accelerated pace for the effective automation development.

As Section 6 ends with the validated proposed improvements, the study proceeds to conclusions.

# 7 Conclusions

This section summarizes the key findings of this study and suggests further steps for the case company. Subsequently, the section proceeds with evaluation of the Thesis.

## 7.1 Executive Summary

For large high-tech manufacturing companies that are experiencing an era of globalization and rapid growth of competition, the superiority of operational processes and effective communication become an integral part of the growth strategy. To address this need and optimize its engineering work, the case company introduced a new 3D engineering software for its three engineering departments several years ago. However, due to the lack of initially developed engineering process in accordance with the new software and operational models of the departments, the company was not able to fully utilize true benefits of the new software. Thus, the objective of this Master’s Thesis was to develop a 3D engineering process for the three departments to undertake mechanical engineering in a coordinated way.

The research process in this Thesis was conducted utilizing the case study approach and qualitative research methodology. The research progressed in accordance with the pre-established stages with defined data collection rounds. The stages are the current state analysis, followed by the literature review and proposal building. The data was collected within the case company and from another company of the case organization by utilizing multiple data collection methods such as workshops, interviews, observations and document reviews.

Based on the results from the current state analysis, a number of weaknesses were identified regarding communication, resources, methods, tools and data quality, as a result of absence of the 3D engineering process as such. During the analysis of the current process development practices in the case company, also strengths areas regarding the environment were identified. Nevertheless, the identified strengths could not be utilized as a result of a lack of resources and communication within the three departments. Based on the identified weaknesses, the literature review focused discussing how to improve the workflow, define roles and responsibilities, and improve communication and collaboration in a cross-functional context. Utilizing the best practice found from literature, the current strengths areas and stakeholder's suggestions, including techniques used by another company of the case organization, the study proposed the cross-functional improvements that the case company can use to develop and deliver an effective engineering work. The eventual outcome of the study relates to developing a new 3D mechanical engineering process for the company's three Engineering departments, taking into account their internal distinctive features in the current organizational environment, and the interests of all parties.

The proposed cross-functional improvements focus on the performance of effective engineering work, for the three departments of the company, within a common 3D engineering process. The process proposes a clear sequence of necessary tasks, with clearly defined roles for each activity, and was built in accordance with the environmental capability and strategy of the company. The proposed process includes such new roles as controller and developer with expanded existing support organization. Moreover, to improve communications and collaboration within the case company, it proposes the creation of new cross-functional groups and committees of controllers and developers. The work of the groups and committees will be focused on information sharing and increasing the level of experience for the further improving of the process. The new roles, their responsibilities and communication practices were set out in accordance with the current state of the environment and the use of popular tools found from literature. Since the proposal building includes a combination of process re-engineering and continuous development, an Action plan was also proposed for implementation of the proposed practices with the focus on the development of 3D engineering automation.

The proposed process was validated twice, with the proposed practices presented and discussed first and then updated in accordance with the real situation in the case company and comments of the responsible persons. The proposed improvements will be implemented according to the created action plan.

This Master's Thesis revealed the difficulties in adapting the new software in engineering processes of the large manufacturing company. By utilizing the proposed improvements, the case company can improve quality of the current mechanical engineering, develop a common standard for performing engineering work, and in the long run reach the level where 3D technology can support engineering process's performance using process re-configurations, and allow the analysis of environmental changes.

## 7.2 Thesis Evaluation

The objective of this Master's Thesis was to develop a 3D engineering process for the three departments to undertake mechanical engineering in a coordinated way. The expected outcome of this study was a new 3D engineering process developed taking into account three engineering departments' internal processes and operating models.

During the study, a general and precise process was developed that can be used by the case company to improve the engineering work and its quality. The initial need for the development of the process was based on the absence of the process as such. Nevertheless, during the analysis of the current situation, it was found that the practice of developing the process is already present in this company. Moreover, the process is developing, despite a slow pace, locally and globally. Thus, the presence of Development group and its attempts to improve the process had also to be analyzed and included in the study as an integral part of the environment. While at the local level, the quality of processes and their characteristics could easily be determined, the simultaneous development of the global environment threatened the entire study and the future of the proposal in connection with the possibility of making decisions at the highest level on the complete reconstruction of the process. Therefore the building of proposal was primarily aimed at developing local practices that can bring improvements in areas that are only partially dependent on global changes in the short term.

During the conducted current state analysis, the operational models of the departments were more thoroughly analyzed in the departments of mechanical engineering than in the department of R&D. Due to the large size of this department and global operation, the internal features of this department were taken only partially, focusing more on the further use of the designed components by Synchronous and Asynchronous mechanical engineering departments depending on the type of product. This, however, does not significantly affect the result of the study, since the effective use of 3D technology is primarily a high priority of mechanical engineering departments. Nevertheless for greater reliability, an analysis of the operational model of R&D department could be carried out more carefully.

The conceptual framework was consistent with the nature of this study and was effectively used during proposal building. Found practices of process modeling with a preliminary assessment of the environment and new characteristics of the process helped to create the apparent logic and integrity of the study. At the same time, the literature review about cross-functional communication and process roles and responsibilities often intersected with each other. This often led to difficulties during the proposal building. As one of the ways to avoid this conflict, these two topics could be combined into one that would reduce the amount of information offered and make the research more transparent.

From the point of view of the proposal building, the conflict consisted also in the need to find a common process, taking into account the internal features of the departments. The needs of different departments differed due to unequal levels of experience of employees and the percentage use of the software. While Asynchronous machines department required more a clearer illustration of the process, Synchronous machines department and R&D stressed the need to create the process automation. This conflict was resolved by means of a textual description of the new groups, roles and responsibilities, and process description with subsequent creation of a detailed action plan for creating parametric and configuration models,. Unfortunately, planned workshops with participation of the maximum number of stakeholders during the proposal building was not possible to conduct as a result of the high level of employment of the majority of respondents. This, in turn, reduced the effectiveness of the final proposal building due to the need to conduct a large number of individual interviews and discussions. However, some workshops in accordance with the proposed action plan will be held after the end of this study, which confirms its reliability.

Next, this sub-section describes evaluation criteria of this study. The study utilizes four evaluation criteria for ensuring trustworthiness and credibility of the data collection, analysis and study overall. The sub-section provides a brief overview of main principles of validity, reliability, logic and relevance as selected evaluation criteria and describes how they were utilized in this work. Considering these four criteria, the study ensures its rigorous approach to research.

*Validity* means the ability of a research method to measure what it is intended to measure. The validity is complete when the theoretical and operational definition is consistent. The total lack of validity makes the study worthless. In that case, the study may examine quite different things than were promised originally. Inadequate validity, therefore, means that empirical observations and the whole study itself are more or less aside from what is meant to be studied.

There are several ways to divide validity into different types depending on author, tradition or research field. As proposed by Yin (2003) four types of validity is one of the most commonly used in academic practice. The four types are internal validity, external validity, construct validity and reliability. To simplify the explanation in this paper, reliability will be considered separately from the validity and will be discussed later in this subsection.

*Internal validity* helps to ensure the significance and consistency of the research results. Researchers should ask to what extent their conclusions are correct and whether competing explanations are possible (Thietart 2001: 196.) Due to a large amount of collected data, which is itself enough to tell something about the subject of study, the internal validity seen as a particular strength of qualitative research (Quinton and Smallbone 2008, 128).

*External validity* is a term used to assess the extent to which the research results are applicable to other contexts. The main question of external validity is whether the results are generalizable or could the results be applied to other contexts and to what extent this may be possible. In case of qualitative studies, external validity is difficult to apply due to subjective and contextual data which aim is a rich description rather than generalizability. Nevertheless, in this kind of research, external validity can be achieved by focusing on an analytical generalization, based on existing specific theory. (Thietart 2001: 201; Quinton and Smallbone 2008, 128.)

*Construct validity* refers to whether the operational measures used in the study are suitable for what it was supposed to measure. For qualitative research, it is also necessary to assess the extent to which research methodology allows to answer the research question. Therefore, before collecting data, it is necessary to determine what to observe, how and why. It is also necessary to clearly define the research question, which will serve as a guide for observations. After that, based on the research question and the existing knowledge, the conceptual framework can be set out. It determines what needs to be studied, and thereby determines the data that needs to be collected and analyzed. The researcher must show that the methodology used to study the research question really measures the dimensions specified in the conceptual framework. (Thietart 2001: 189.)

In this study, to ensure validity, the type of material and methods are chosen according to theoretical and methodological tradition. The study utilizes multiple sources of evidence by using data triangulation. The interviews, participant observations, internal documentation review, and workshops provided a foundation for the detailed analysis of the obtained information and data. Evidence of documentation was used to verify the evidence obtained during the interviews. All involved stakeholders were selected based on their position and level of experience in accordance with recommendations of the heads of the departments. In this thesis, generalization was made by reflecting the re-search results within the conceptual framework created by utilizing the existing knowledge, which also related to findings from the CSA.

*Reliability* refers to the ability of used research method and metrics to obtain the same findings in the case of a repeat of the study, or if it is carried out by another researcher. (Quinton and Smallbone 2008, 129). As with the case with validity, the reliability of qualitative researches is difficult to measure because of the nature of the approach. The reliability of such studies depends on honesty and integrity of the researcher in describing the whole research process. In this case honesty is an attitude that refers to accurate observation and data recording, truthful reporting, especially in the phases which relate to data analyzing and explanation. (Thietart 2001: 199-200.)

In this study, reliability was planned to be increased by using different data sources and collection tools with data collecting at different points of time. All stakeholders had a voice in findings' evaluation to ensure the outcome is fair and unbiased by the researcher. During the data collection rounds, collected data was grouped into a database with a visual interpretation of for example interview details such as circumstances, duration, and source.

In addition to validity and reliability, the logic and relevance are considered to ensure a quality of this research. The logic of this study can be seen as a step-by-step implementation of predefined steps that are graphically represented in the research design diagram Figure 1. Detailed explanation and aim of each step are described in Sub-section 2.2.

According to Myers (2009) relevance means that a research should never be done for frivolous, wasteful or irrelevant purposes. The research is "relevant" if its main objective is to understand or explain reality, that is - underlie a research problem. (Thietart 2001:

118) In this study, the case company has identified the business challenge which defined the objective. The expected outcome was discussed in advance before initial research design and approach selection. The relevance was focused on ensuring consistency between the objective and outcome and cross-checked during evaluation by stakeholders involved in this research which led to the creation of a final proposal.

## 7.3 Closing Words

This Thesis emphasizes the importance of a strategic and constructive approach in the development of a process related to engineering work in case of the introduction of new software in a large manufacturing company. This study shows the logic and implications of building a new process in the context of several departments on a local scale, also taking into account their internal features and partly the impact of the global environment.

During the research process, the study revealed dependence of effectiveness of the company's operational processes on the maturity of its organizational culture, data control practices, and quality of methods for performing the necessary tasks. In practice, importance of these engineering tasks is often blurred, or lost in the entire order-delivery process, seemingly due to their merely operational significance.

At the same time, this part of the production connects all aspects of creating value for the customer and has a direct impact on the company's profitability. With the help of the cross-functional practices proposed in the study, the company can take control over the creation of data, develop an enabling environment for effective cooperation and collaboration, and in the long-term develop an optimal common engineering platform. Such a well-functioning platform will bring a wonderful ability to easily and seamlessly integrate new elements of the business portfolio, which is especially important for large manufacturing companies in the rapidly changing environment.

## References

Bititci, U., Ackermann, F., Ates, A., Davies, J., Garengo, P., Gibb, S., MacBryde, J., Mackay, D., Maguire, C., van der Meer, R., Shafti, F., Bourne, M. and Umit Firat, S. (2011). Managerial processes: business process that sustain performance. *International Journal of Operations & Production Management*, 31(8), pp.851-891.

Bijwaard, D.J.A., Spee, J.B.R.M. and Boer P.T. (2000). *Engineering Workflow The Process in Product Data Technology*. National Aerospace Laboratory. 10 p. Available from: https://ris.utwente.nl/ws/portalfiles/portal/6123054 [Accessed 24 Mar. 2018].

Blomqvist, M. (2017) Process Development: Session 1. [Lectures to MEng Industrial Management program 2017], Metropolia University of Applied Sciences, Autumn.

Creswell, J.W. (2014). *Research design: qualitative, quantitative, and mixed methods approaches*. London [etc.]: Sage Publications.

Davenport, T.H. (2005). The Coming Commoditization of Processes. *Harvard Business Review*. Vol. 83(6), 100–108.

Dul, J. and Hak, T. (2008). *Case study methodology in business research*. 1st ed. Boston: Elsevier.

Gimenez-Espin, J., Jiménez-Jiménez, D. and Martínez-Costa, M. (2013). Organizational culture for total quality management. *Total Quality Management & Business Excellence*, 24(5-6), pp.678-692.

Hall, J.M. and Johnson, M.E. (2009). When Should a Process Be Art, Not Science? *Harvard Business Review*. Vol. 87(3), 58–65.

Hammer, L. and Stanton, S. (1999). How Process Enterprises Really Work. *Harvard Business Review*. Vol .77(6), 108–118.

Hammer, M. (2007). The Process Audit. *Harvard Business Review*. Vol. 85(4), 111–123.

Imeche.org (2018). *Definition of mechanical engineering - IMechE*. [online] Available at: https://www.imeche.org/membership-registration/become-a-member/definition-of-mechanical-engineering [Accessed 24 Mar. 2018].

Kappos, A. and Croteau, A.M. (2002). Organizational change and culture: Insights on BPR projects. *AMCIS 2002 Proceedings.* pp.2076-2084.

Kesler, K. (2016). *Design Smart Decision-Making into the Organization (and Forget RACI)* | Kates Kesler Organization Consulting. [online] Kateskesler.com. Available at: http://kateskesler.com/design-smart-decision-making-into-the-organization-and-forget-raci/ [Accessed 24 Mar. 2018].

Khan, M. S., Al-Ashaab, A., Shehab, E., Haque, B., Ewers, P., Sorli, M., Sopelana, A. (2013). Towards lean product and process development. *International Journal of Computer Integrated Manufacturing* 01 December 2013, Vol.26(12), p.1105-111

Klaus, N. and Kumta, G. (2014). *Knowledge management*. London [etc.]: Springer International Publishing.

Maroofi, F., Nazaripour, M. and Maaznezhad, S. (2012). Links Between Organizational Culture and Six Sigma Practices. *Links Between Organizational Culture and Six Sigma Practices.* Vol. 2(4) pp.83-101.

Marshall, C. and Rossman, G. (2006). *Designing qualitative research*. 4th ed. Thousand Oaks: Sage.

Martinsuo, M. and Blomqvist, M. (2010). *Process Modeling for Improved Performance.* Aalto University. 25 p. Available from: http://lib.tkk.fi/Reports/2010/isbn9789526033792.pdf [Accessed 24 Mar. 2018].

O'Gorman, K. and MacIntosh, R. (2015). *Research methods for business and management.* Oxford: Goodfellow Publishers Ltd.

O'Neill, P. and Sohal, A. (1999). Business Process Reengineering: A review of recent literature. *Technovation*, 19(9), pp.571-581.

Quinn, R.E., Rohrbaugh, J. A Spatial Model of Effectiveness Criteria: Towards a Competing Values Approach to Organizational Analysis, *Management Science*, (29:3), 1983, pp. 363-377.

Quinton, S. and Smallbone, T. (2008). *Postgraduate research in business: A Critical Guide*. London [etc.]: Sage Publications.

Rogers, P. and Blenko, W. (2006). Who Has the D?: How Clear Decision Roles Enhance Organizational Performance. *Harvard Business Review*. Vol. 87(3), 58–65.

Sharp, A. and McDermott, P. (2009). *Workflow modeling*. Boston: Artech House.

Smart, P., Maddern, H. and Maull, R. (2009). Understanding Business Process Management: Implications for Theory and Practice. *British Journal of Management,* 20(4), pp.491-507.

Staats, B. R. and Upton B.R. (2011). Lean knowledge work. *Harvard Business Review.* Vol. 89(10), 100–110.

Thiétart, R. (2001). *Doing management research: a comprehensive guide*. London [etc.]: Sage Publications.

Ullman, D. (2010). *The Mechanical Design Process*. Boston: McGraw-Hill Higher Education.

Van Der Aalst, W. (1998). The Application Of Petri Nets To Workflow Management. *Journal of Circuits, Systems and Computers,* 08(01), pp.21-66.

Yin, R. (2003). *Applications of case study research*. Thousand Oaks: Sage Publications.

## Summary of Field notes for Data 1 (Informants 1-4)

<table>
<tr><th></th><th>Topic(s) of the interview</th><th>QUESTIONS</th><th>FIELD NOTES<br>Synchronous machines mechanical engineering</th><th>Asynchronous machines mechanical engineering</th><th>R&D</th></tr>
<tr><td rowspan="4">1</td><td rowspan="4">Starting point:</td><td>What is the role of the department in organization?</td><td colspan="3" rowspan="15">CONFIDENTIAL</td></tr>
<tr><td>What kind of interactions the department have with other departments in terms of 3D engineering process?</td></tr>
<tr><td>What kind of products to be designed?</td></tr>
<tr><td>How many people are using this software?</td></tr>
<tr><td rowspan="3">2</td><td rowspan="3">Interviewee’s EXPERIENCE</td><td>What is your role in the current process?</td></tr>
<tr><td>What are responsibilities?</td></tr>
<tr><td>Why have you been chosen to be at this position?</td></tr>
<tr><td rowspan="3">3</td><td rowspan="3">Investigate how the software was taken into use</td><td>What are the main reasons of using the new 3D engineering software and 3D engineering software overall?</td></tr>
<tr><td>How the process is improved?</td></tr>
<tr><td>What is the goal if exists?</td></tr>
<tr><td rowspan="3">4</td><td rowspan="3">Clarify the inputs and outputs of the process development</td><td>What are the expertise and resources that are involved?</td></tr>
<tr><td>How could we improve the process?</td></tr>
<tr><td>How would you evaluate the results, immediate and long-term?</td></tr>
</table>

| | | | |
|---|---|---|---|
| **5** | **Key strengths** | **Is the current process successful, from your point of view? What works? Why do you think so?** | CONFIDENTIAL |
| | | **What can be considered as indicators of success for current process?** | |
| | | **What are the company's strengths in the process?** | |
| **6** | **Key concerns** | **If you feel it is not successful, what are the reasons?**<br>**What are the key concerns about the current process that take place?** | |
| **7** | **Analysis** | **Is it even possible to improve work quality and productivity of 3D engineering?** | |
| | | **In which areas do you think there is space for improvement? In what way?** | |
| | | **Who or by whom could these possible improvements be done / implemented in your opinion?** | |
| | | **What areas would you recommend engineers and engineering teams focus on to become more efficient in 3D engineering?** | |
| | | **In your experience, what is the most common waste engineers can, and should, eliminate from their 3D engineering workflows?** | |
| | | **What is a help chain and how would it work in an 3D engineering process?** | |
| **8** | **Best practice** | **Did the company introduce any best practice?**<br>**What best practice do you think the company should follow as for the process development?** | |
| **9** | **Development needs** | **How could the company avoid the problems in case of a new software introduction?** | |
| **10** | **To add** | **What would you like to add that we have not yet discussed?** | |

# Field notes for Data 1 (Informant 5)

| Details | | | |
|---|---|---|---|
| **Name (code) of the informant** | | | Global application manager |
| **Position in the case company** | | | Global application manager |
| **Date of the interview** | | | 23.1.2018 |
| **Duration of the interview** | | | 39 min |
| **Document** | | | Field notes |
| | **Topic(s) of the interview** | QUESTIONS | FIELD NOTES |
| **1** | **Starting point:** | **What is the role of the department in organization?** **What kind of interactions the department have with other units in terms of 3D engineering process?** **Can you please briefly describe the process?** | CONFIDENTIAL |
| **2** | **3D practices** | **Why do your department do activities globally?** **What is the quality of our processes at the moment compared to other units?** | |
| **3** | **Key strengths** | **What are the main strengths of the process?** | |
| **4** | **Key concerns** | **What are main concerns?** | |
| **5** | **Analysis** | **In which areas do you think there is space for improvement? In what way?** | |
| **6** | **Best practice** | **What best practice do you think the company should follow as for the process development?** | |
| **7** | **To add** | | |

# Field notes for Data 1 (Informant 6)

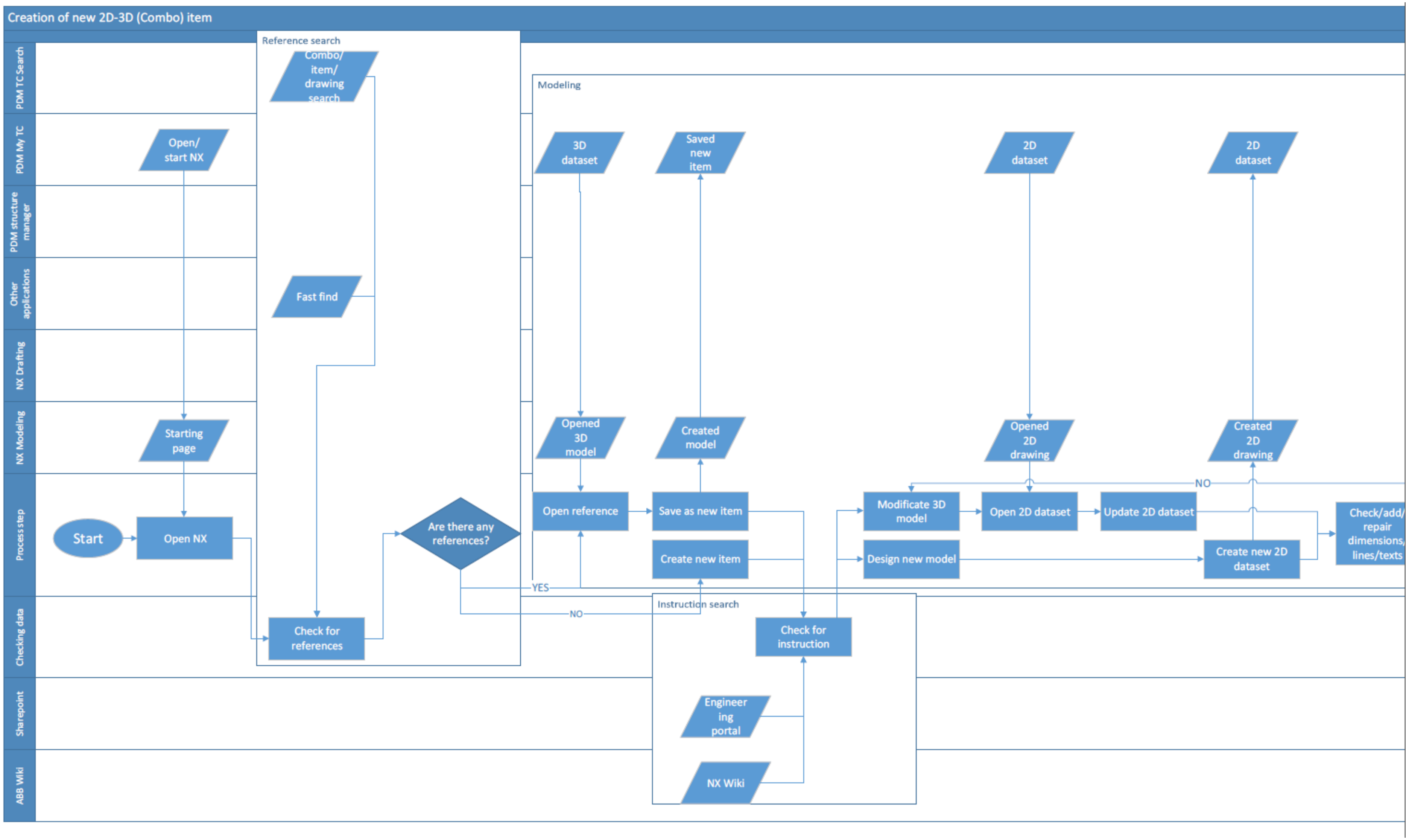
| | | | |
|---|---|---|---|
| Details | | | |
| **Name (code) of the informant** | | Head of R&D department (Second company) | |
| **Position in the case company** | | Head of R&D department | |
| **Date of the interview** | | 1.2.2018 | |
| **Duration of the interview** | | 62 min | |
| **Document** | | Field notes | |
| | **Topic(s) of the interview** | QUESTIONS | FIELD NOTES |
| **1** | **Starting point:** | **What kind of products to be designed?** | CONFIDENTIAL |
| | | **Please describe the process itself:**<br>**How does this happen?**<br>**How process was developed?** | |
| **2** | **Investigate how the software was taken into use** | **How the process is improved or developed?**<br>**What is the goal if exists?**<br>**Are there core logical steps of the process improving or development? If yes, what they are?** | |
| **3** | **Clarify the inputs and outputs of the process development** | **What are the expertise and resources that are involved?**<br>**What are the requirements for participants?** | |
| **4** | **Key strengths** | **Is the current process successful, from you point of view? What works? Why do you think so?**<br>**What can be considered as indicators of success for current process?** | |
| **5** | **Key concerns** | **If you feel it is not successful, what are the reasons?** | |
| **6** | **Analysis** | **In which areas do you think there is space for improvement? In what way?**<br>**What tasks do 3D engineers spend their time on, and how should that work be changed or redistributed?**<br>**In your experience, what is the most common waste engineers can, and should, eliminate from their 3D engineering workflows?** | |

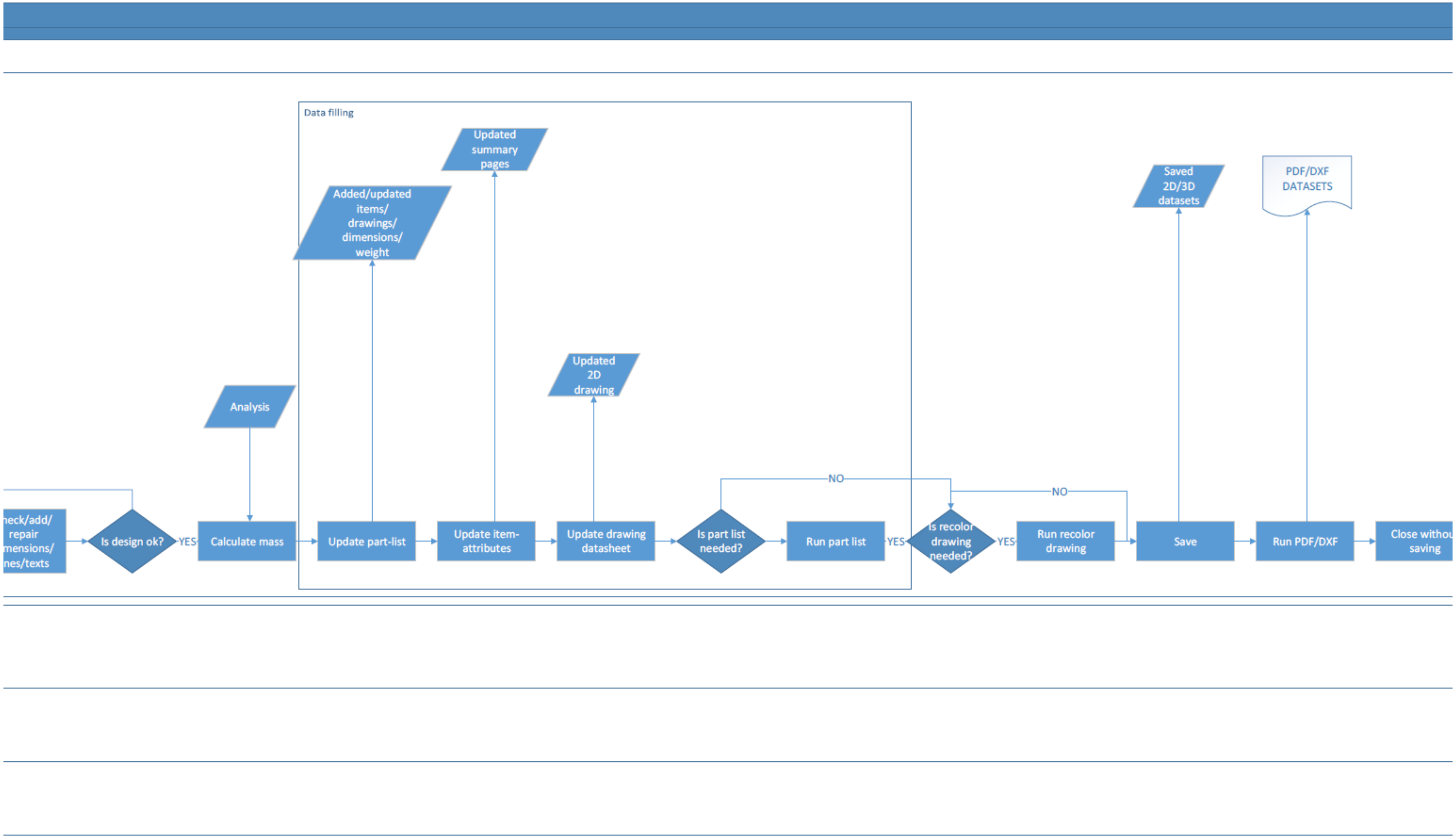
| | | | |
|---|---|---|---|
| | | **What is a help chain and how would it work in the 3D engineering process?** | CONFIDENTIAL |
| **7** | **Best practice** | **Does the company have (internally) some guide-lines of how to do it?**<br>**What best practice do you think the company should follow as for the process development?** | |
| **9** | **To add** | **What would you like to add that we have not yet discussed?** | |

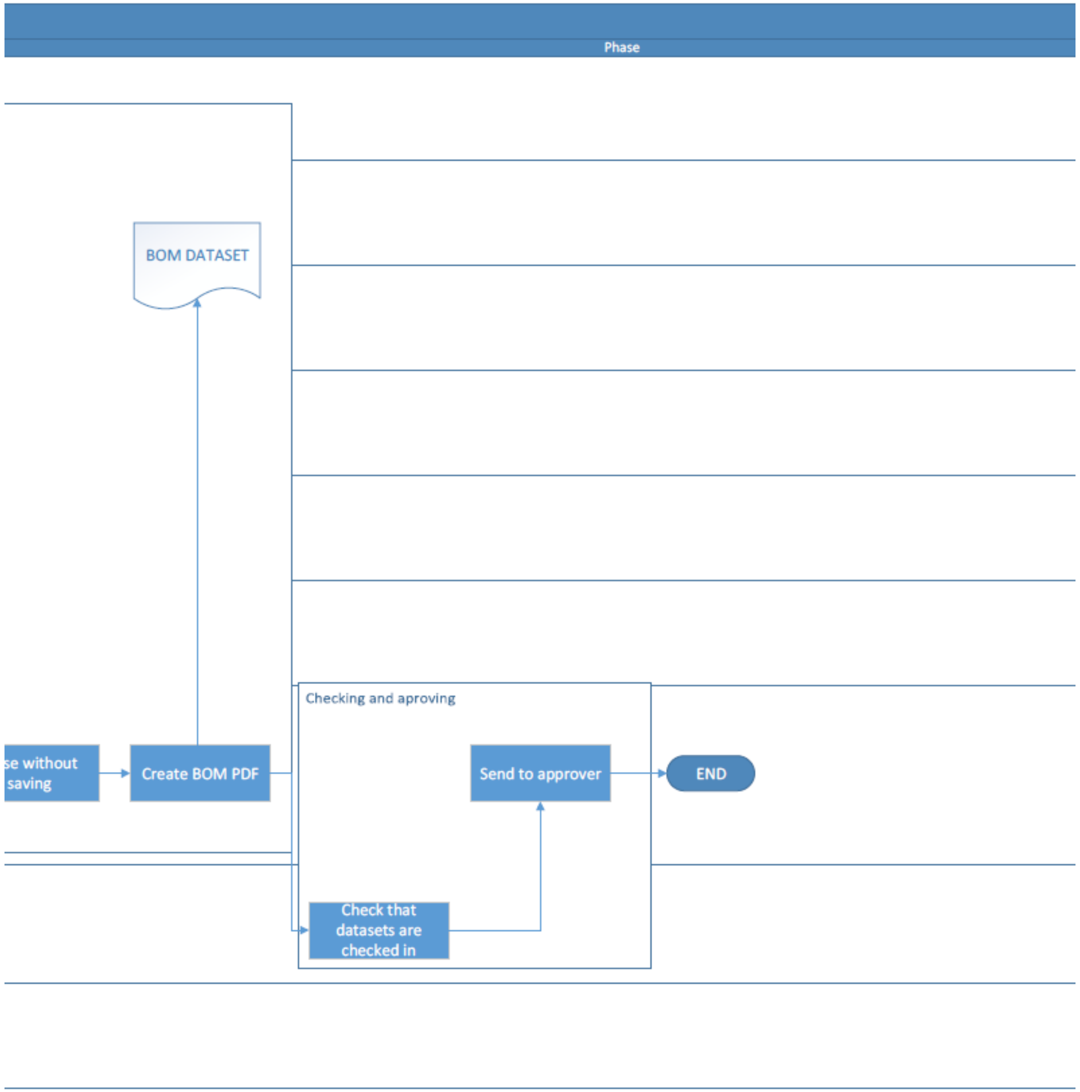
## Field notes for Data 1 (Informant 7)

| | | |
|---|---|---|
| Details | | |
| **Name (code) of the informant** | | Head of Asynchronous machines engineering department |
| **Position in the case company** | | |
| **Date of the interview** | | 8.2.2018 |
| **Duration of the interview** | | 10 min |
| **Document** | | Field notes |
| | QUESTIONS | FIELD NOTES |
| **1** | **How would you evaluate the current 3D engineering process?** | CONFIDENTIAL |
| **2** | **What are the department's strengths in the process?** | |
| **3** | **What are the department's key concerns about the current process that take place?** | |
| **4** | **How important using of 3D software is for the department?** | |
| **5** | **What are department's internal resources for process development?** | |

**Current 3D mechanical engineering process**.




Data filling
Updated summary pages
Added/updated items/ drawings/ dimensions/ weight
Analysis
Updated 2D drawing
Saved 2D/3D datasets
PDF/DXF DATASETS
heck/add/ repair mensions/ nes/texts
Is design ok?
YES
Calculate mass
Update part-list
Update item-attributes
Update drawing datasheet
Is part list needed?
NO
Run part list
YES
Is recolor drawing needed?
NO
YES
Run recolor drawing
Save
Run PDF/DXF
Close withou saving

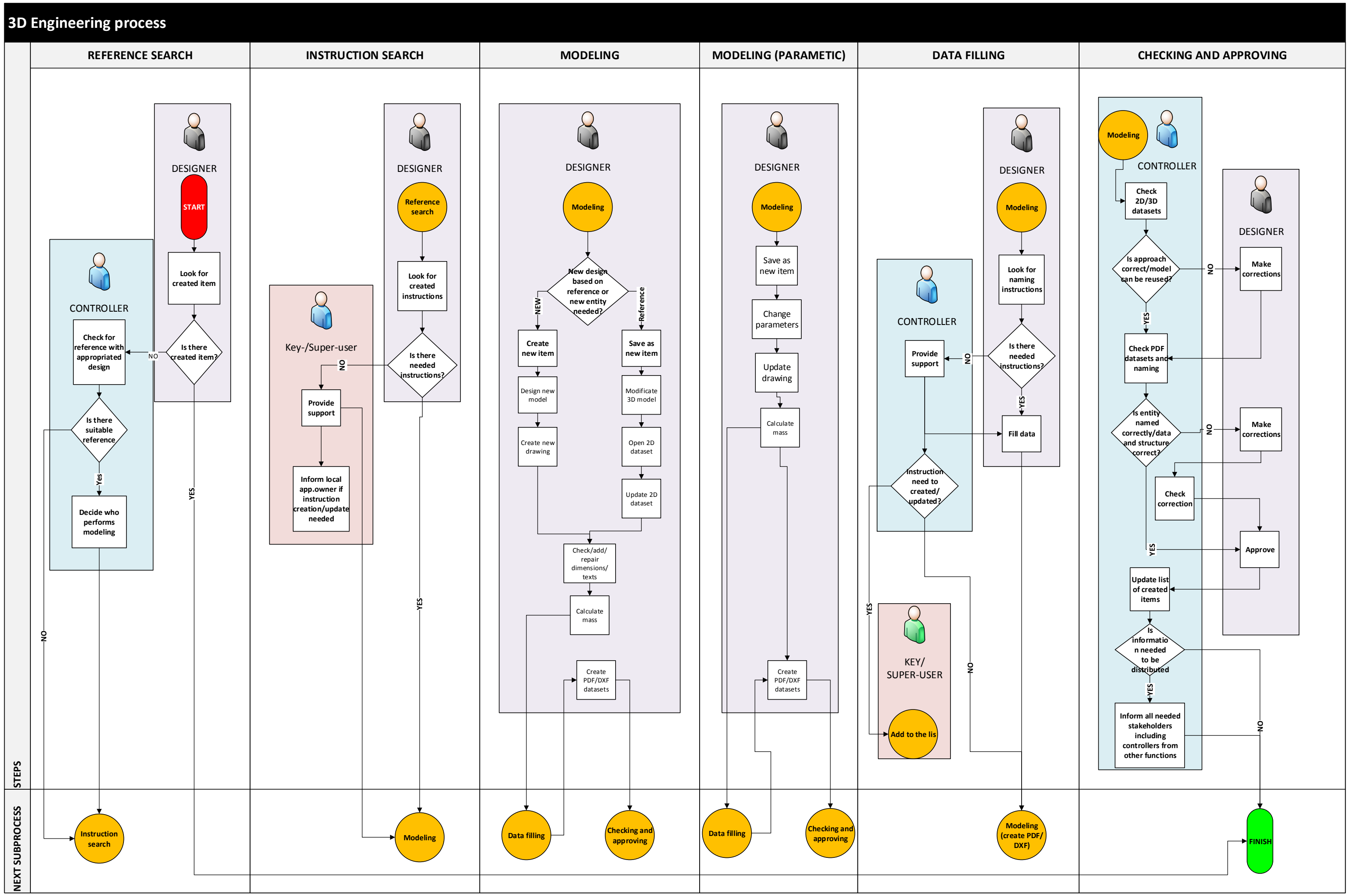

Phase
BOM DATASET
Checking and aproving
se without saving
Create BOM PDF
Send to approver
END
Check that datasets are checked in

## New process characteristics (Data 2).

| | Suggested process characteristics and their impact on process enablers | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Sugges-tions | Workflow design | Information Technologies | Motivation & Measurement | Human Research | Policies & Rules | Facilities | Feasibility & Notes |
| 1. | Roles for data checking and control | Requires clear process description with marked roles | Listings and data storage places, communication tools need to be standardized | User resistance? | Roles distributed among performers | Common rules needed for data checking and control | Need of common system for easy data search and storage | Easy to implement, require clear design and communication before implementation |
| 2. | Rules for parametric models creation | Full-time performers needed | User friendly models needed | | Resources needed. Who perform? Team or individuals? | Common standards and techniques used | Models storage into available system | Difficult to implement, require time and resources, great potential and engineering time reduction |
| 3. | Cross-organizational teams (based on similar types of products) | Areas of common interest need to be defined | Communication systems need to be defined | Desire to collaboration is needed | Named individuals | Communication approach is standardized and documented | | Both, informal and formal communication should be utilized. Requires interconnection with process owners |
| 4. | Naming instructions | New entities named according to instructions | Common instructions available for whole organization | | Who is responsible for creation and maintenance? | Whom naming principle utilized? | Where instruction are saved? | Looking for common approach may be difficult. Compromise need to be found |
| 5. | Roles and responsibilities shown in profile | | Need to be updated if changed | user resistance | | Idea interconnected with company's strategy | | Roles and responsibilities need to clearly established |
| 6. | Only official instructions in use | There is only one instruction/design | Only one place where instructions are | Lack of desire to use instructions | | general instructions or depending on the model | Where instruction are saved? | Easy to implement, common rules need to be established |
| 7. | Creation of 3D standard items | | | | Resources/time needed | | | |
| 8. | 3D models from subcontract manufacturer (Bearings, sensors) | In what stage/how need to be ordered? | Type of the 3D model. Solid body? | | | How to be added to the system? | | Easy to implement, requires desire form purchasing, engineer and subcontractor. Costs/free? |
| 9. | Common training sessions for 3D engineers | How to be conducted? | Materials/exercises? | Desire and motivation required. No need to conduct for everyone. | Who conduct? Internally/externally? | | Where materials will be saved? | Requires prepared material, experience of training and suitable material for engineers from different department |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 10. | Support chain presentation for 3D engineers | Kept once during team meeting? | Presentation and structure need to be available from ims/eng.portal? | | | Presented always if changed. | Local appl.owner updates and maintain? | Easy to implement, no additional costs or resources. |
| 11. | Instructions created jointly by all engineering departments | There is need to recognize common design possibilities. | There is only one place where instructions are saved. | Motivation of key/super users to teamwork and collaboration | requires named roles from each department | Clear rules for instruction created? Internal differences? | Instructions will be presented during team meetings by key/super users. | Requires common interest finding and strong communication and teamwork skills. Instructions needed to be reviewed by performers before publishing. |
| 12. | Creation of new 3D entity requires approving by controller | Additional step in workflow | What communication tool? | | Requires additional roles in departments for different types of products | Clearly described process needed. | | Easy to take data under control. Requires deep analysis of designed products. |
| 13. | All decision about system or process development require approving by all departments | Key stakeholders from all departments participated in steering committee. | Decisions needed to be documented in intra, easy available for stakeholders. | | 3D/CAD Key/super users defined in each department | | | Requires compromise and difficult situation may appear. Continuous dialog needed to be established. |

## New 3D mechanical engineering process map (Final Proposal).



## Description of roles, responsibilities, and cross-functional groups and committees (Final Proposal).

| Role | Responsibility | Allocation | Available resources |
|---|---|---|---|
| Controller *(Proposal)* | - Responsible for control over the created data in own component areas, including checking and approving of new entities<br>- Responsible for created data review, listing, maintenance and distribution, working closely with internal and cross-functional controller and developer groups<br>- Works under the guidance of own department's manager representing meetings<br>- Responsible for decision-making about who is eligible for particular data creation in own component areas<br>- Points out the needed proposals for data control improvement and corrective activities together with other controller group's members, developers and super-users | 10% | ~… |
| Developer *(Proposal)* | - Responsible for local 3D CAD process development and maintenance according to policies and rules established by application owners<br>- Responsible for parametric models' creation, testing and maintenance<br>- Works under the guidance of the Local Application Owner and own department's manager representing meetings<br>- Together with the Super-user and Local Application owner points out the needed instructions and trainings during new product development stage<br>- Actively participates in design approach's assessing and creation of new 3D entities<br>- Responsible for data harmonization project, including initial data review and listing, closely collaborating with other developer group's members and controllers group | 100% | 3 |
| Key-users *(Existing)* | - Responsible for application training, instructions and induction of new users<br>- Responsible of 1st level user support<br>- Works under the guidance of the Local Application Owner representing meetings | 20% | 3-4 |
| Super-users *(Existing)* | - Responsible for application training, instructions and induction of new users. Based on Local Application Owner's instructions, communicates the application changes to the local organization.<br>- Responsible of 1st level user support. When needed, transmits queries and support requests to global support organization working as a contact person between local users and Global Support organization<br>- Works under the guidance of the Local Application Owner representing meetings<br>- Point out the needed proposals for application improvement and corrective activities together with Local Application Owner.<br>- Working as a main responsible for user acceptance testing in local site.<br>- Specifies and maintains local test cases and testing activities.<br>- Secure that the local site will be fully compatible with the other sites in BU and its architecture as a whole will be appropriate, secure, continuous and reliable. | 40% | 3 |
| Local appli-cation owner *(Existing)* | - Overall responsible of the local PDM site<br>- Arranges necessary application training, support, operation and maintenance work in the local PDM site including all installations (servers/clients) and environments (production/test/development)<br>- Keeps local key user community strong enough and agree clearly the named persons with their superiors/line managers<br>- Owns the contract in case of local agreements with internal or external service providers<br>- Verify the quality of service deliveries from internal or external service providers and take corrective actions, if needed<br>- Provide input to frame agreements with service providers, if needed. | 50% | 1 |
| Global ap-plication owner *(Existing)* | - Ensuring that the engineering tools provide the right functions and capabilities for new and existing products developed in R&D for efficient order engineering in all manufacturing locations<br>- Providing support for development and maintenance of common engineering tools<br>- Supporting new product development and product transfers | 50% | 1 |

| Role | Description | Method of communication and information sharing | Frequency/timing of communication |
|---|---|---|---|
| Controller Group *(proposal)* | Cross-functional group, created on the basis of common interest in terms of certain component area. The group includes controllers from different sub-units, working with same component areas. The group includes representatives of minimum two sub-units, including always mechanical engineering department and R&D. The group's goal is to create a continuous and stable dialogue between stakeholders, to find common interest areas, a common approach, to share knowledge among other functions and eliminate double work by taking the creation of new data under control with the help of cross-functional cooperation and collaboration.<br><br>With the help of the group, different approaches to solving similar problems can be combined into the most effective approach, forming the best practice, which can be utilized later in new product development. Group works closely with developer group during data harmonization and creation of parametric models. | OneNote<br>Informal meetings and types of communication | Always during new product development:<br>- review of initial idea<br>- review of initial design<br>- review of created entity<br><br>Always during existing design update.<br><br>Always when new 3D entity for standard item need to be created. |
| Controller commettee *(proposal)* | Cross-functional group, created on the basis of common interest and efficient product development and support. The committee includes representatives of controller groups involved in the design of certain machine type (Synchronous or Asynchronous). The purpose of the group is to cover improving of existing design or design being developed. The committee's goal is to create an initial dialogue with the stakeholders involved in the mechanical engineering and R&D for the further effective performance of work.<br><br>The committee includes representatives of the support staff to provide the necessary technical assistance for optimizing of engineering design work. | OneNote<br>Formal meetings | Always during new product development:<br>- review of initial idea<br>- review of initial design<br>- review of created entity<br><br>Always before, during and after major improvement or update of existing design |
| Developer group *(proposal)* | Cross-functional group, created on the basis of common interest. The group includes representatives of different sub-units, including mechanical engineering departments and R&D. The group's goal is to efficiently develop needed parametric models, jointly with controllers harmonize created data and support new product development and creation of standard 3D items including importing of subcontract elements to the system.<br><br>The group's absolute target is to build stable, reliable and predictable environment to improve the profitably of the company through effective implementation of engineering tasks resulting in an improved design quality of the products. | OneNote<br>Formal and informal communication | Meetings need to be held weekly, in addition to everyday communication. |
| Steering committee | Cross-functional committee, consisting of local support's members from mechanical engineering departments and R&D with representatives of Global Support organization. The committee determines necessary improvements or ideas for development and requests them from Global Support organization. The committee's goal is to define good 3D working practices and document them to the internal knowledge database. | OneNote | Meeting are held monthly, in addition to everyday formal and informal communication |

## RACI table.

| R= Responsible A= Accountable C= Consulted I= Informed | Designer | Key-user | Super-user | Controller | Developer | Department manager | Local application owner | Global application owner |
|---|---|---|---|---|---|---|---|---|
| **New product development** | | | | | | | | |
| Review of initial idea | - | I | C | C | C | - | I | C |
| Review of initial design | I | I | C | C | C | I | C | C |
| Review of needed instruction/trainings | I | C | R | C | R | I | A | C |
| Review of created entities | C | C | R | R | R | I | I | C |
| Distribution of new entities | I | I | I | R | R | A | I | C |
| Maintenance of created entities | I | I | I | R/I | R/I | I | I | C |
| | | | | | | | | |
| **Standard item creation** | | | | | | | | |
| Review of created items | R | - | - | I | I | - | - | - |
| Creation of new entity | I/R | I | I | A/R | C/R | - | I | I |
| Review of created entity | I | I | I | R | R | - | I | I |
| Distribution of new entity | I | I | I | A/R | R | I | I | I |
| Maintenance of created entities | I | I/C | I/C | A/R | C/R | I | I | I |
| | | | | | | | | |
| **Instruction creation** | | | | | | | | |
| Review of initial need | C | R | R | - | C | - | A/R | A |
| Review of common interests | - | R | R | - | C | - | A/R | A |
| Creation of instruction | - | R | R | - | C | - | A | I |
| Review of created instruction | C | R | R | - | C | - | R | I |
| Distribution of instruction | I | R | R | - | I | I | R | A |
| Maintenance of created instruction | I | R | R | - | I | - | R | I |
| | | | | | | | | |
| **Parametric model creation** | | | | | | | | |
| Review of entity's variability | C | - | I | C | R | I | A | I |
| Review of common interests | C | - | I | R | R | I | A | C |
| Review of best practices from other units | - | - | I | I | I | - | I | R |
| Decision on internal/external creation | - | I | C | - | C | C | R | A |
| Creation of new model (if internally) | - | I | C | C | R | - | C | I |
| Review of created model | C | C | C | R | I | - | A/R | A/R |
| Testing of created model | I | R | R | C | R | - | A/R | A/R |
| Distribution of created model (internally) | I | R | R | I | I | I | R | A |
| Distribution of information (for other units) | - | - | - | - | - | - | I | R |
| Maintenance of created model | - | I | R | I | R | - | C | I |
| | | | | | | | | |
| **Data harmonization** | | | | | | | | |
| Review of initial need | C | - | - | R | R | A | C | I |
| Review of created items | C | - | - | R | R | - | - | - |
| Data listing | C | C | C | A | R | - | I | I |
| Data review | C | C | C | - | R | - | - | - |
| Data distribution | I | I | I | R | A | I | I/C | I/C |
| Data maintenance | I | I | I | R | C | A | I | I |

## Cross-functional resource classification model (Final Proposal)